UNIVERSITY OF ALBERTA

GEOLOGY AND GROUNDWATER RESOURCES OF THE GRIMSHAW-CARDINAL LAKE AREA, ALBERTA

by

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A thesis submitted to the Faculty of Graduate Studies in partial fulfilment of the requirements for the degree of Master of Science.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Geology and Groundwater Resources of the Grimshaw-Cardinal Lake Area, Alberta," submitted by Orest Tokarsky, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The Grimshaw-Cardinal Lake area is underlain by clastic rocks of Cretaceous age. Surficial cover includes buried channel fill, glacial and postglacial deposits. Three levels of channel deposits are recognized. The uppermost level constitutes a broad plain, in which the Grimshaw gravels are overlain by a thin cover of till. The intermediate level deposits include deposits within the Berwyn Channel and deposits of other, smaller tributaries to the deeply buried Shaftesbury Channel, as well as buried terrace remnants of this channel. The most deeply buried channel deposits are considered to be the youngest of the three levels of deposits.

Surficial cover is thin over the Whitemud Hills and thickens away from them. Till is predominant in the uplands. Three major glacial lakes existed within the map-area following glacial retreat: Lake Falher up to the 2,000-foot level on either side of the Peace River, glacial Lake Cardinal in the vicinity of the present-day Cardinal Lake, and Lake Whitemud in the vicinity of Whitemud River. A few low, broad earth mounds which may be collapsed pingos are found in low-lying areas associated with lacustrine deposits of glacial Lake Falher.

The Grimshaw gravels form the major aquifer within the area. Intermediate level channel deposits, and sandstones of the Upper Cretaceous Dunvegan Formation, also are utilized as aquifers. The Whitemud Hills and the areas underlain by the Grimshaw gravels are topographically high and constitute areas of recharge. Groundwater quality is best in these areas and deteriorates rapidly away from them. Groundwater from the Grimshaw gravels generally has a total solids content of under 6000 parts per million. Poor quality groundwater is found

in areas adjacent to the major rivers which constitute regional discharge areas. Groundwater in the major discharge areas usually has excessive amounts of one or all of: total solids, sulphates, and iron. The total solids content is usually in excess of 2,000 parts per million.

The saturated thickness of the Grimshaw gravels averages about 30 feet. A transmissibility of over 300,000 igpd/ft was calculated from a 4-day pump test in a locality where the saturated thickness was 52 feet. A 20-year safe yield of well over 1,000 igpm was calculated from this test. This is considered to be a very tentative value, since the pump test was carried out at much too low a pumping rate to enable application of this value with assurance. Greater well loss at higher pumping rates and possible barrier boundary effects with increased pumping time would adversely affect the yield. Two-hour bail tests were conducted at other localities within the area of the Grimshaw gravels, and all indicate that a very high yield is possible. Bail tests conducted on aquifers within the Dunvegan Formation and within the intermediate level deposits of the Berwyn Channel indicate transmissibilities of 1,060 and 164 igpd/ft and safe yields of 36 and 5 igpm, respectively.

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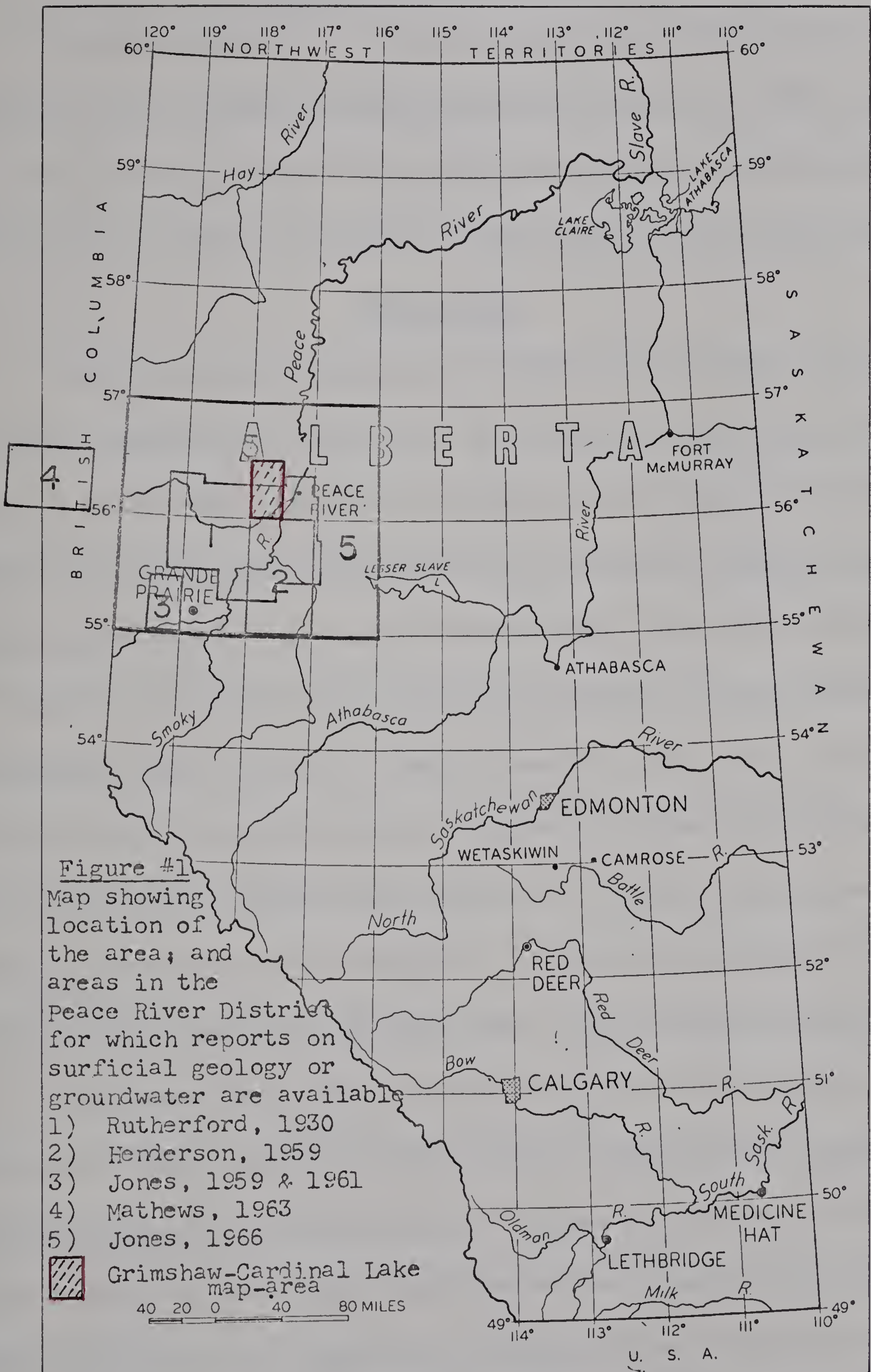

Figure #1

Map showing location of the area; and areas in the Peace River District for which reports on surficial geology or groundwater are available

1) Rutherford, 1930
2) Henderson, 1959
3) Jones, 1959 & 1961
4) Mathews, 1963
5) Jones, 1966

Grimshaw-Cardinal Lake map-area

GROUNDWATER DIVISION OF THE RESEARCH COUNCIL OF ALBERTA

INTRODUCTION

Location and Extent of Area

The area studied (Fig. 1), covering approximately 625 square miles, is bounded by latitudes 56°00' and 56°30' north and by longitudes 117°30' and 118°00' west. It is covered by National Topographic Series map-sheets 84C/4 and 84C/5, and includes all or parts of townships 81 to 86, ranges 23 to 26, west of the 5th meridian.

Physiography

The map-area makes up a part of the plains area of Alberta. The Whitemud Hills in the northern part of the area rise to elevations of slightly over 2,700 feet above sea level. North of these hills the Whitemud River flows on a broad flood-plain between 2,000 and 2,100 feet above sea level before it becomes incised into a steep-sided valley on its journey to the Peace River. South of the Whitemud Hills is a broad flat plateau-like plain caused by the remnants of a gravel upland (refer to topography shown on Encl. 1). Cardinal Lake lies on this plain. From the edge of the plain, the land slopes uniformly southeastwards to the edge of the Peace River valley at about 1,800 feet above sea level. The Peace River has entrenched itself into a valley whose floor lies below 1,100 feet above sea level. Short tributary streams drop rapidly through steep-sided valleys to join the Peace River.

The Peace River provides the major drainage out of the map-area; it flows northwards eventually to enter the Arctic Ocean. The Smoky River, another major river, just crosses the southeastern corner of the map-area and enters the Peace River a short distance east of the area. The Whitemud River is next in size to the Peace and the Smoky but is not a large river. Drainage from the Whitemud Hills is northward into the Whitemud River through Cardinal Creek. Numerous short tributary streams

flow southeastward from the edge of the gravel-capped plain into the Peace River. Some of these tributaries originate from springs flowing out of the gravels, or from muskegs formed by seepage out of the gravels at the edge of the plain.

Climate and Soils

The climate of the Grimshaw-Cardinal Lake area is characterized by cold winters and moderately warm summers. The mean annual temperature is not available for any place within the area, but at Fairview, Alberta, 15 miles to the west (elevation 2143 feet above sea level), it was 34.2°F for the 30-year period 1921-1951. The mean temperature for this period for the three coldest months, December through February, was 6.7°F and for the three warmest months, June through August, was 54.9°F. The mean annual precipitation over the same period was 17.92 inches at Fairview and 13.15 inches at Peace River. Most of this is fairly evenly distributed throughout the growing season, and although total rainfall is low, moderate summer temperatures help to keep evaporation and transpiration low. Mean frost-free days range from 60 in the northern part of the map-area to more than 80 in the southern part.

Both rainfall and temperature vary locally. Within the Grimshaw-Cardinal Lake area, the greatest variation would be expected between the top of the Whitemud Hills and the bottom of the Peace River valley. Daily precipitation is recorded at the fire lookout tower in the Whitemud Hills (l.s.d. 1, sec. 1, twp. 86, rge. 1, W6th Mer., elevation about 2720 feet above sea level) for about 6 months out of every year. The precipitation for the period April 1st to September 30th amounted to 19.53 inches in 1964 (a wet year) and to 9.65 inches in 1965 (a dry year). For the same time interval, the precipitation at Peace River Airport (elevation 1860 feet), amounted to 15.60 inches in 1964 and 7.60 inches in 1965. Rainfall records kept at Peace River town (elevation 1104 feet) are incomplete for the time intervals referred to, although

precipitation appears to average approximately the same, or slightly less, than at the Peace River Airport. Precipitation at Fairview amounted to 15.73 inches in 1964 and 9.97 inches in 1965 for the same time span.

Soil types within the map-area range from undifferentiated Podzolic soils over the Whitemud Hills, Grey and Dark Grey Wooded soils across the broad plain south of Whitemud Hills, to Grey and Dark Grey Wooded Solods on gentle slopes off the Whitemud Hills and between the broad plain south of Whitemud Hills and the Peace River (M.D. Scheelar, personal communication). Gleysolic soils and Sphagnum bogs are developed in low-lying areas.

Population and Industries

Agricultural settlement in the Grimshaw-Cardinal Lake area did not begin until the early 1900's, and the area is still relatively sparsely settled. The principal towns, Grimshaw, Berwyn, and Brownvale, are located on the Northern Alberta Railway right-of-way and are connected by highway #2. Their respective populations in 1961 were 1,095;347; and 237. The population of Grimshaw had increased to 1,515 in 1964. Data are not available for Berwyn and Brownvale for 1964.

Agriculture is the principal industry. A sawmill is located at Smith Mills and a planing mill near Grimshaw. Grimshaw is a trucking center for points in northern Alberta. Some service companies engaged in oil exploration activity in regions to the north of the map-area are located in Grimshaw.

Purpose of Study

This study was undertaken to delineate the extent, and to determine the potential yield of thick water-bearing gravels within the area. Because the surficial geology of the area had to be known for proper evaluation of these gravels, mapping of the surficial materials was undertaken. This was supplemented by as much subsurface information as could be obtained. Other water-bearing zones are present and

important within the mapped area, but the greatest yields are to be expected within the gravels and the emphasis of the work was placed on these.

Methods of Investigation

Prior to the start of the field work, a preliminary photogeological map of surficial features was made. This map was used to determine the localities where field checking had to be done. The few reported water-well logs available were plotted on a base map. Other drilling information, primarily from seismic shot-hole drillers' logs was compiled. Field work involved surficial mapping, test drilling, and the conducting of a well inventory together with the collection of water samples where possible.

Previous Work

The earliest published geological work within the area was that of Dawson (1882), who conducted a reconnaissance of the British Columbia and Alberta portions of the Peace River district which extended from Edmonton to Fort Simpson, N.W.T. McLearn (1918, 1919, 1926, and 1945) published work on the Cretaceous succession in this and adjacent areas.

Other geological studies within the map-area and/or its environs have been carried out by: Allan (1922, 1928); Stelck and Wall (1954, 1955); Stelck, et al (1958); Wickenden (1951); Wall (1960); Burk (1963); Green and Mellon (1962); Gleddie (1954); Alberta Study Group (1954).

The surficial geology of the area has been briefly treated by Rutherford (1930), Taylor (1958, 1960) and Jones (1966). Henderson (1959) has mapped in detail the surficial deposits of the Sturgeon Lake map-area adjacent to the Grimshaw-Cardinal Lake area on the south. Jones (1961) and Mathews (1963) have mapped surficial deposits in areas to the southwest (the Beaverlodge district of Alberta) and to the west (the Fort St. John area of British Columbia), respectively (Fig. 1).

A preliminary soil survey report which included the map-area was published by Wyatt (1935). A more recent report by M.D. Scheelar is being prepared.

Groundwater resources of the area have been studied by Rutherford (1930), and by Jones (1966) as part of investigations covering larger areas. Both writers commented on the general availability of groundwater in quantity in the Grimshaw-Cardinal Lake area.

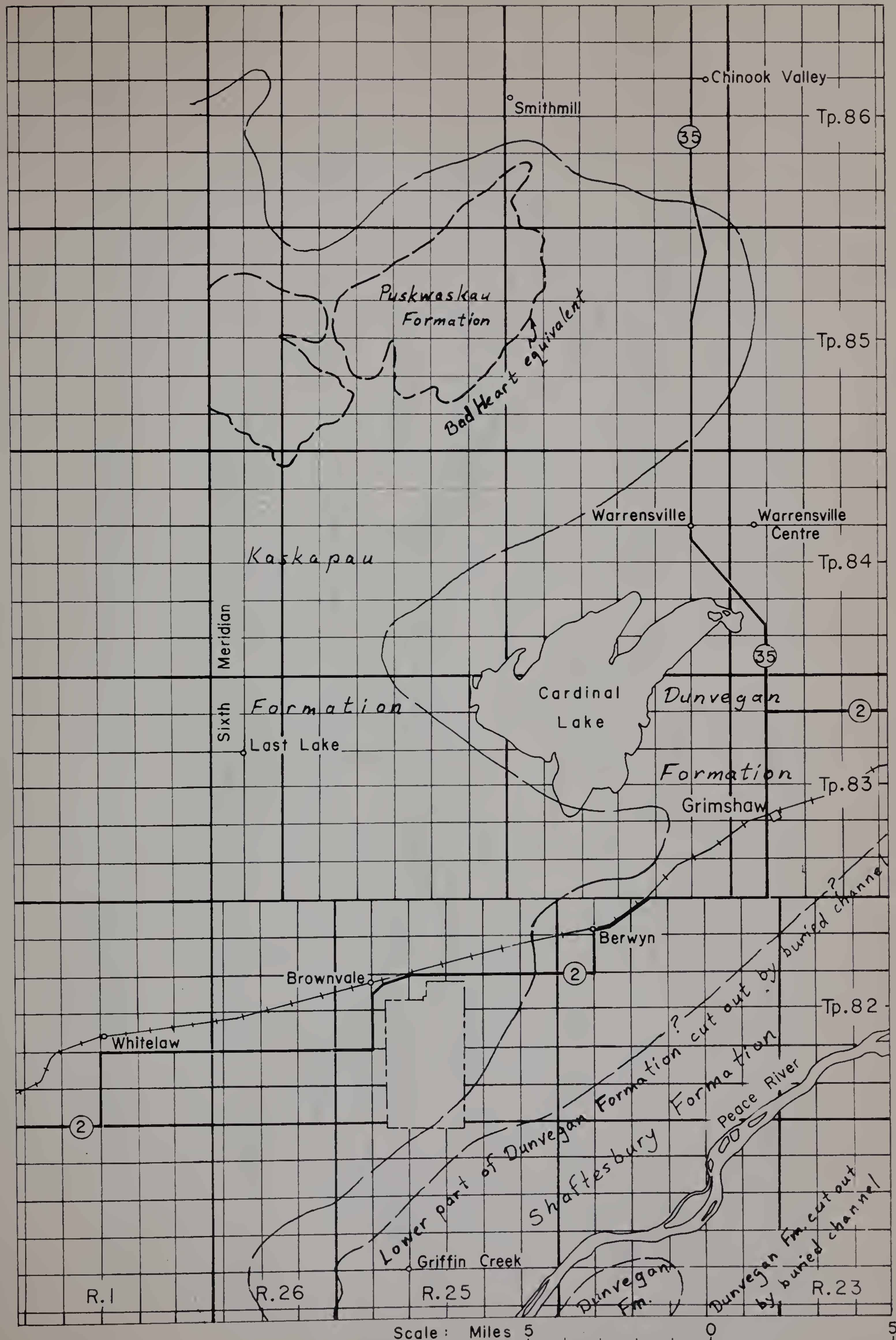

Figure 2 Subcrop map of bedrock geology

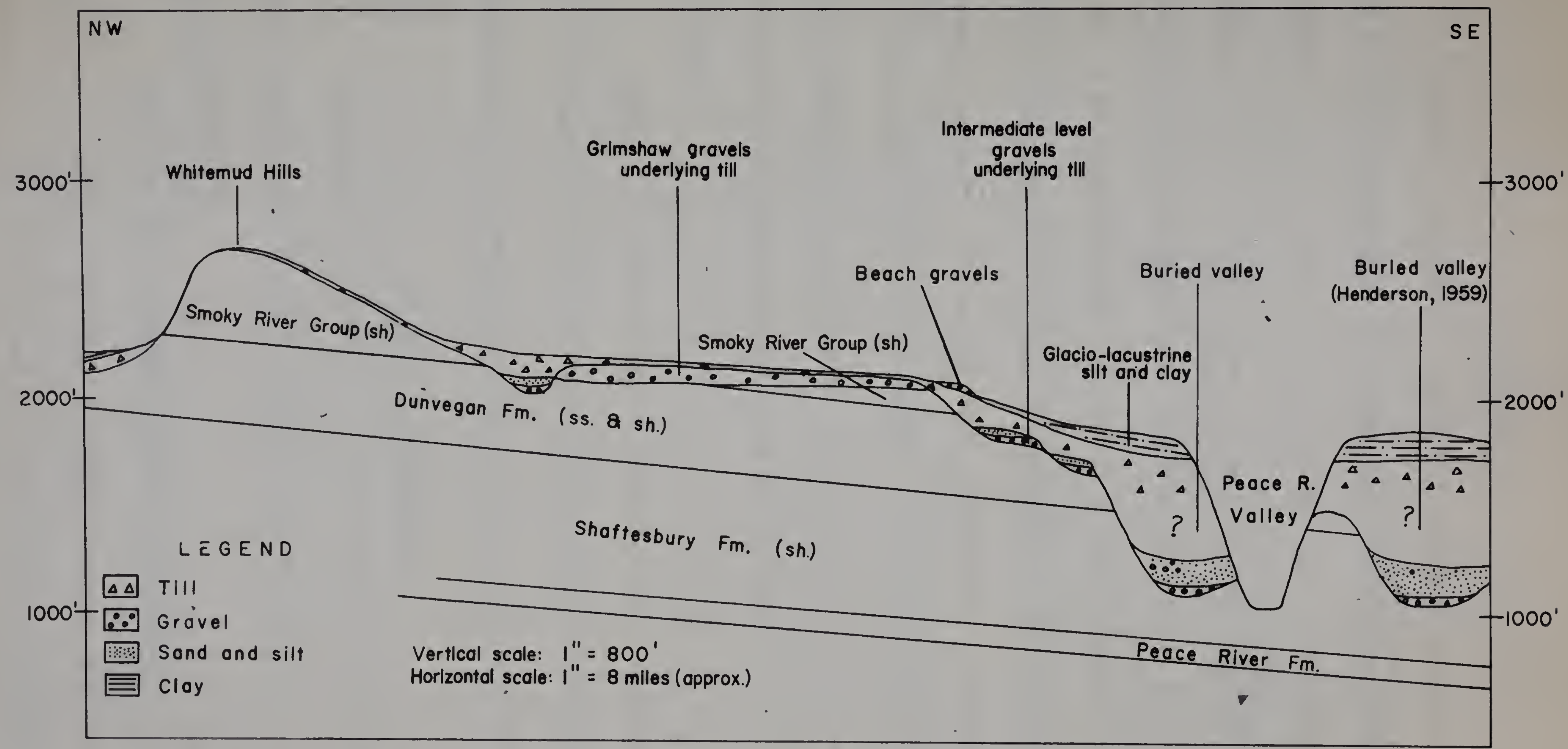

Figure 3 - Generalized NW - SE geological cross-section, Grimshaw-Cardinal Lake area

GEOLOGY

Introduction

The area is underlain by Upper Cretaceous rocks mantled by thin glacial deposits in the Whitemud Hills and thicker glacial and Recent deposits in other areas (Table 1, Encls. 1, 2, 3, and 4, Fig. 2). Lower Cretaceous rocks are near the surface in the Peace River valley. A deeply buried river valley trends northeastward across the area northwest of the present-day Peace River valley (Fig. 3, Encl. 4). A prominent high broad terrace to this buried valley lies a few miles northwest of the edge of the valley, approximately 1,000 feet above the thalweg of the buried channel. This terrace forms a plateau-like plain lying between the Peace River valley and the Whitemud Hills. The terrace deposits consist dominantly of gravel intermixed with sand and are herein termed the Grimshaw gravels. Intermediate level gravels and sands occur locally below the level of the Grimshaw gravels.

Figure 2, the subcrop map of bedrock geology, was constructed by utilizing intersection points of structure contours drawn on the top of the formations represented and topographic contours drawn on the top of bedrock.

Cretaceous Stratigraphy

Cretaceous formations that underlie the area are shown in table 1, figure 2, and enclosures 3 and 4. These are discussed below.

Peace River Formation

The Peace River Formation crops out approximately 7 miles east of the map-area in the valley of the Peace River near the town of Peace River. At the east edge of the map-area it comes to within 200 feet of the land surface adjacent

Table 1. Table of formations (expanded from Green and Mellon, 1962)

Era	Period or epoch	Rock unit			Thickness (feet)	Lithology
Cenozoic	Recent				0-100+	River alluvium and terrace sand, silt, gravel; lacustrine and flood-plain sand, silt, clay; muskeg; eroded slopes, slump and slide debris
Cenozoic	Pleistocene				0-650	Till; glaciofluvial sand & clay; glaciolacustrine clay, silt, sand, gravel
Cenozoic	Tertiary	Buried channel deposits		Deeply buried	0-350+	Gravel, sand, silt, clay. Grimshaw gravels and the intermediate level deposits form important aquifers in Grimshaw area.
		Buried channel deposits		Intermediate level	0-100+	
		Buried channel deposits		Grimshaw gravels	0-130	
Mesozoic	Upper Cretaceous	Smoky River Group	Puskwaskau Formation		0-130	Shale, dark grey, fissile
		Smoky River Group	Bad Heart equivalent		0- 10	Sandy shale, greenish; siliceous shale & black rusty sandstone
		Smoky River Group	Kaskapau Formation	upper member	0-230	Shale, dark grey, fissile
		Smoky River Group	Kaskapau Formation	lower member	0-140	Sandy & silty shale; whitish sandstone
			Dunvegan Formation		0-405	Sandstone, soft, grey; grey, silty carbonaceous shale; the only important bedrock aquifer in Cardinal Lake-Grimshaw area
			Shaftesbury Formation	upper member	0-460	Silty shale, grey; thin laminated siltstone
	Upper Cretaceous / Lower Cretaceous		Shaftesbury Formation	lower member	270-460	Shale, black fissile; fish scales horizon near top
	Lower Cretaceous		Peace River Formation	Paddy member	40-80	Sandstone, poorly sorted carbonaceous; one or more thin shaly or coaly zones
			Peace River Formation	Cadotte member	60-85	Sandstone, massive, fine grained to very fine grained sandstone
			Peace River Formation	Harmon member	40-70	Shale, dark grey; thin lenses of siltstone & very fine grained sandstone

to the Peace River. The formation is made up of three members. The Paddy sandstone, a continental carbonaceous sandstone, is the uppermost member. This is underlain by the marine Cadotte sandstone member, and the Harmon shale is the lowest member.

Shaftesbury Formation

The oldest exposed rocks within the map-area are the dark grey marine shales of the Shaftesbury Formation. Small outcrops occur along the valley of the Peace River. The thickness of the formation, as determined from electric logs, is variable within the map area: 860 feet in the northwest, 840 feet in the southwest, and 770 feet in the northeast.

Green and Mellon (1962) divided the Shaftesbury Formation into upper and lower members. The contact between the two members in subsurface is marked by a prominent electric log "kick" which in the Cardinal Lake-Grimshaw area lies 60 to 100 feet above the base of the Fish Scales sandstone marker horizon (a commonly used marker bed in electric log correlation). Stelck, et al (1958, p. 18) place the Upper-Lower Cretaceous boundary at the top of the Fish Scale sandstone marker bed.

The shales of the upper member of the Shaftesbury Formation become progressively more silty upwards, and grade into the Dunvegan Formation.

Dunvegan Formation

This formation is composed of grey, fine- to medium-grained, poorly consolidated sandstone interbedded with silty shale. The thickness of the Dunvegan Formation ranges from 360 feet to just over 400 feet over the map-area. The contact with the overlying Kaskapau Formation is sharply defined but apparently

conformable (Gleddie, 1954, p. 495; Green and Mellon, 1962, p. 9). An electric log correlation (Encl. 3) indicates an interfingering relationship. Stelck (1962) considered the Dunvegan Formation to be essentially deltaic in origin with a source of sediment in the Cassiar-Omineca uplift in British Columbia. The eastern edge of sand deposition within this sequence lies approximately 60 miles to the east and 70 miles to the southeast of the Grimshaw-Cardinal Lake area (Burk, 1962).

Smoky River Group

Kaskapau Formation

The dark grey fissile marine shales of the Kaskapau Formation crop out in a number of places in the Whitemud Hills. A yellowish efflorescence on the weathered outcrops is common. A lower predominantly sandy member up to 140 feet thick can be distinguished on electric logs.

Bad Heart Formation

The Bad Heart Formation proper does not appear to be present in the map-area. However, drill holes that were put down in the Whitemud Hills indicate the presence of up to 10 feet of greenish sandy shale, siliceous shale, and thin black rusty sandstone which is probably Bad Heart equivalent (Table 1, Fig. 2).

Puskwaskau Formation

Soft dark grey shales, up to 130 feet thick, overlie Bad Heart equivalent in the Whitemud Hills. These shales form the lower part of the Puskwaskau Formation, and are the uppermost Cretaceous strata exposed in the map-area.

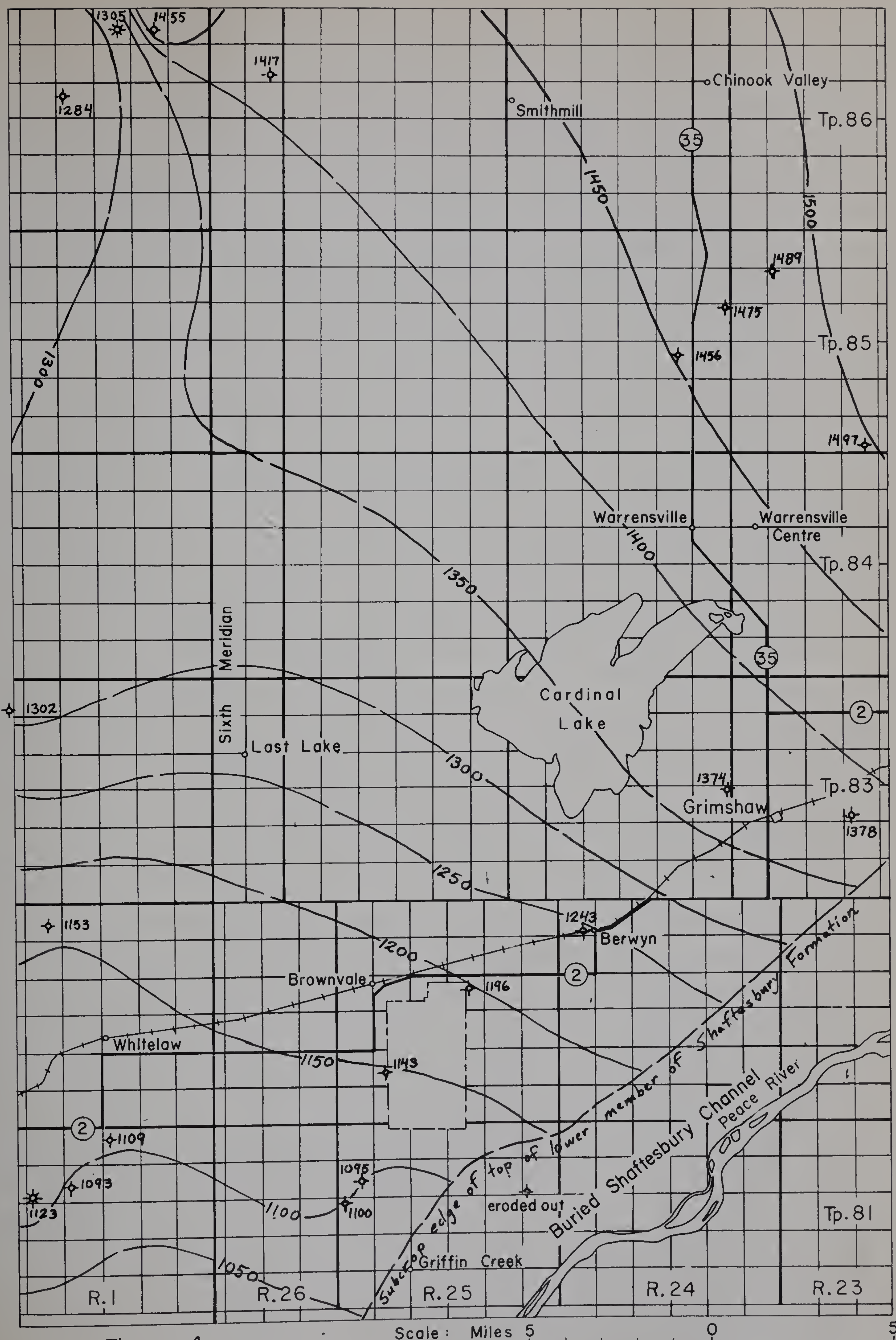

Figure 4
Structure contours on top of lower member of Shaftesbury Formation

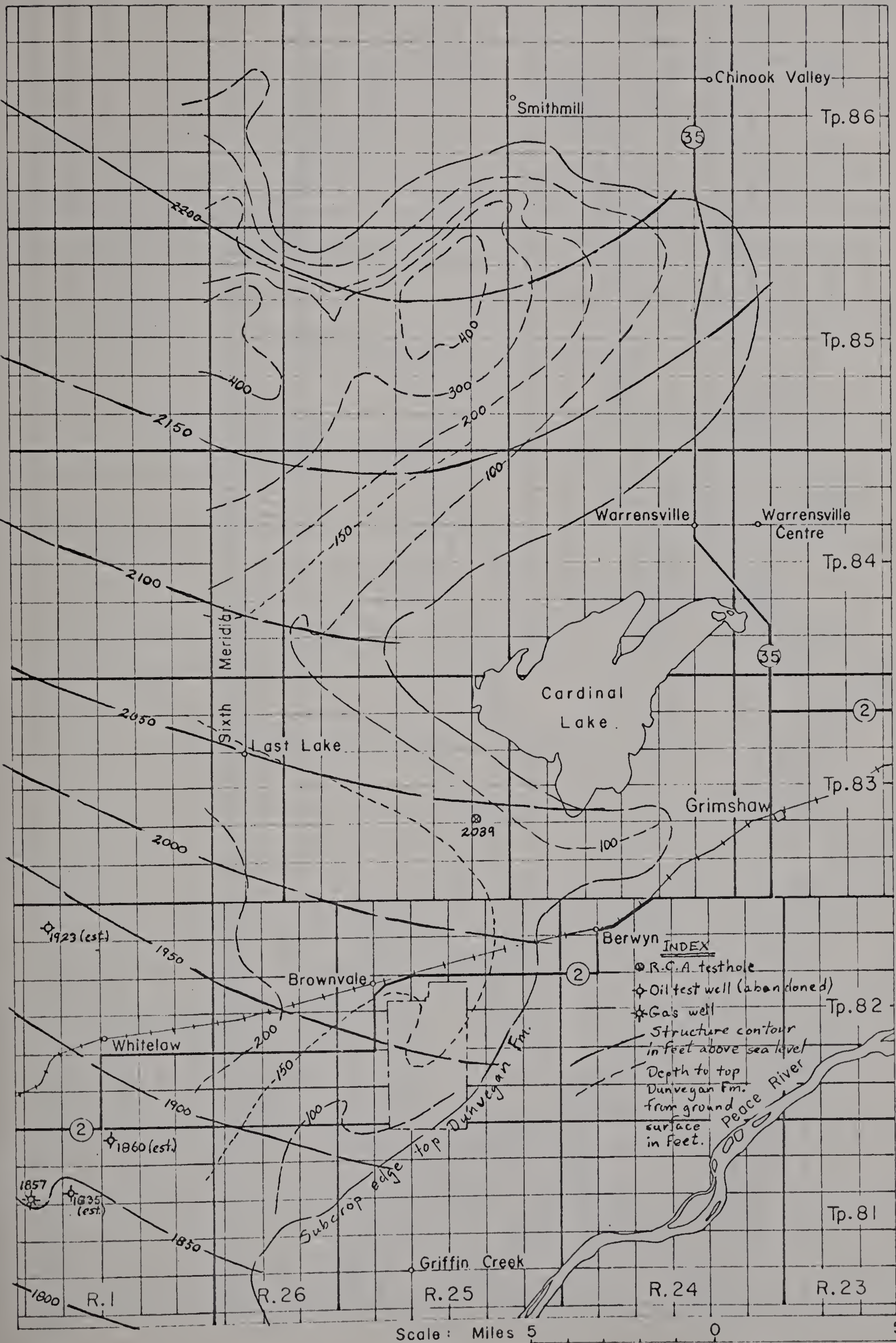

Figure 5 - Structure contours on top of the Dunvegan Formation.

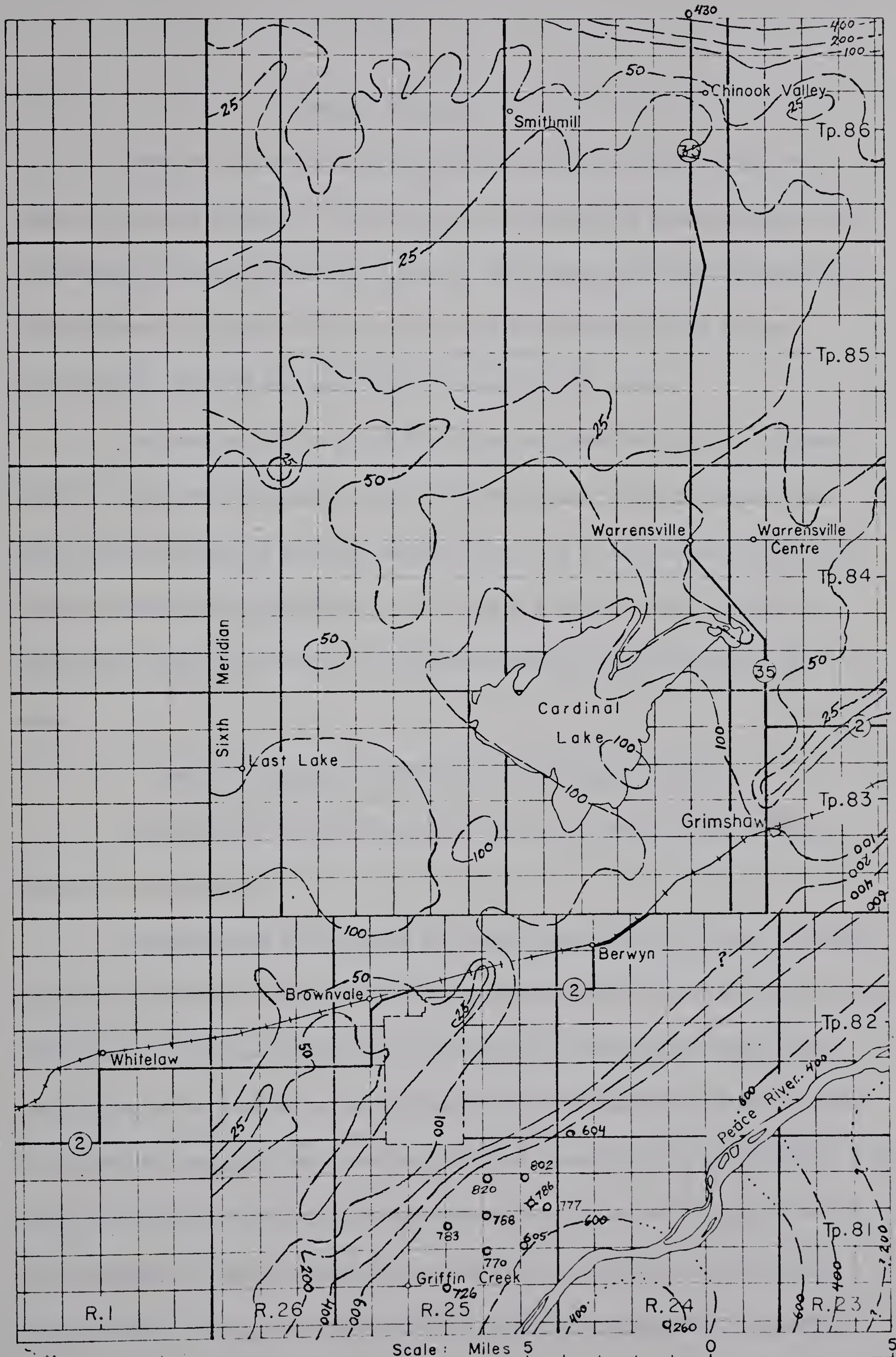

Figure 6 - Thickness of surficial deposits
o 430 Control point and thickness of surficial material (in feet)
Note: only control points within Shaftesbury Channel are shown.

Bedrock Structure

Structure contour maps have been drawn on two horizons within the Upper Cretaceous sequence. The structure on the top of the lower member of the Shaftesbury Formation is shown on figure 4. The regional dip is approximately to the southwest, at a gentle 8 feet per mile over the northern half of the area, steepening to about 25 feet per mile in the southwestern corner.

The structure on the top of the Dunvegan Formation is shown on figure 5. Electric log control lies entirely west of the map-area. Only one electric log pick within the limits of the area could be made. As a result of poor control the contour trends are only approximate. The map is included mainly to indicate approximate depths to the top of an important water-bearing formation in the area.

Bedrock Topography and Thickness of Surficial Deposits

A map showing the configuration of the buried bedrock land surface is presented as enclosure 5.

A map showing the thickness of surficial deposits (Fig. 6) was constructed based on the points of intersection of surface contours and of contours drawn on top of bedrock as well as using thicknesses obtained from control points used in the construction of the bedrock topography map. The term "surficial deposits" is used here to refer to unconsolidated residual, alluvial, lacustrine or glacial deposits which overlie bedrock and includes all buried channel deposits as well as glacial and post glacial deposits. The greatest thicknesses of surficial deposits are found within buried valleys. A map showing the surficial geology is presented as enclosure 1.

It should be noted here that the existing National Topographic Series maps with 50-foot contours have inaccuracies in the contouring in places. To correct for this, and to provide closer contour spacing, a 10-foot contour interval map was constructed utilizing seismic shot-hole elevations, highway profiles, and existing bench marks. This map has been used in the construction of all maps in which surface topography was necessary for their construction.

Method of Construction and Reliability of Maps

The chief sources of data in the construction of the bedrock topography and drift thickness maps were seismic shot-hole drillers' logs and structure test-hole electric logs supplemented by water-well drillers' logs, outcrop sections, and data obtained by test drilling.

Logging of bedrock in the case of seismic shot-hole logs and water-well drillers' logs is considered to be usually reliable. However, bedrock is logged in only a few holes, whereas it was probably encountered in a great many holes. Often it is possible, with field checking, to make a bedrock pick from a log that does not indicate bedrock. The reasons for lack of recognition of bedrock by drillers are:

1) Shales within the Dunvegan Formation which underlie much of the map-area are usually soft and without marked fissility, making them difficult to recognize as shale. In addition, they are usually silty and have a greyish or brownish cast and resemble the less stony phases of the overlying till. The sandstones of this formation are often poorly consolidated and soft and are easily mistaken for surficial sand. In the Whitemud Hills, shales of the Smoky River Group comprise the bedrock. These shales are dark grey, fissile, and usually only slightly silty. They are more easily recognizable as bedrock than are the shales

of the Dunvegan Formation. However, there is usually an interval of 5 feet or less at the drift-bedrock contact of soft, weathered shale in which fissility is slight or absent. This weathered zone is difficult to recognize as bedrock.

2) All shot holes and many water wells have been drilled with small rotary rigs. Caving of till and pebbles mixed with soft bedrock makes accurate logging of the top of bedrock difficult.

3) In the case of water wells, distinction between clay, till, and shale is not extremely important to many drillers because none is likely to yield much water. Similarly, in the case of aquifers, the driller is not too interested in knowing whether water is obtained from surficial sand or from loosely consolidated bedrock sandstone as long as water is obtained. In both seismic and water-well drilling accurate logging usually is not insisted upon by the customer and samples of cuttings are seldom taken. In most cases, especially in seismic drilling, close visual examination of cuttings is not made.

4) Many drillers have learned logging techniques through their own experience or from other drillers and have formed their own terminology which is often misleading, usually lacks details, and sometimes is completely wrong. It is difficult and, in some cases, impossible to translate their terms into accepted geological terms. For example, a sequence of lacustrine clay, till, and shale is commonly logged as clay and rocks, as clay and boulders, or as clay throughout. Occasionally it may be logged correctly as clay, clay and rocks, and shale, or less correctly as clay (or clay and boulders), hard clay. In the last case, a bedrock pick can be made on top of the hard clay, but only if there is other evidence to support it.

In the map of bedrock topography (Encl. 5) the contours in some areas are considered to be reliable; in other areas they are much less so. Four areas may be distinguished by the type of control available, as follows.

Whitemud Hills

Contours over the area of the Whitemud Hills are judged to be fairly reliable, although the elevations may be a little too low because of the presence of soft weathered shale at the top of the bedrock; this weathered material is usually logged as drift. In this area most shot-hole logs indicate a thin cover of clay over "hard clay". The "hard clay" has been interpreted as shale, mainly of the Smoky River Group, for the following reasons:

1) A number of holes that were drilled to locate possible ferruginous sandstones, and were sampled and described in detail, indicate shale at shallow depths.

2) Numerous outcrops of shale and sandstone have been examined and one test hole has been drilled which encountered bedrock at a shallow depth.

Flanks of Whitemud Hills

In the area off the flanks of the Whitemud Hills to the north, south, and east where the bedrock formations are the Dunvegan Formation and the lower member of the Kaskapau Formation, contours showing the elevation of the top of the bedrock are judged to be less reliable than in the area of Whitemud Hills. The reduced reliability is the result of fewer points of control because drift cover is thicker and fewer holes have penetrated bedrock. Also, the rocks of these formations are more difficult to recognize as bedrock. Checks on driller's logs are provided by: a few outcrops, test drilling off the south flank of Whitemud Hills, and by structure test-hole electric logs. The exact drift-bedrock contact usually cannot be made from the electric logs but it can be approximated with

a fair degree of certainty due to the presence of local marker beds within the Dunvegan Formation. It is much more difficult to interpret drillers' logs in this area. Consequently, interpretation was held to a minimum. Holes that logged bedrock directly were used for control points. "Clay with hard ledges" or "with sandstone ledges" was logged in many holes and was interpreted, in most cases, to indicate bedrock, although in some cases these "ledges" may be slabs of sandstone or other rock enclosed in till. "Black sand" or "black water sand" or "sandrock" was logged in a few holes and usually was interpreted to mean sandstone of the Dunvegan Formation. In addition, in a few holes "clay" or "hard clay" underlying gravel or sand and gravel usually was interpreted as bedrock.

<u>Area underlain by Grimshaw gravels and intermediate level sands and gravels</u>

Within the area of the Grimshaw gravels, few holes penetrate bedrock. However, from test drilling it is evident that sand and gravel lies directly on bedrock in most cases. Deep holes that penetrate thick gravel and sand and enter material that is logged as "clay" or "clay with hard ledges" are probably bottomed in bedrock. Checks on drillers' logs are provided by test drilling and by a few structure test-hole electric logs. In places where channels cut through the terrace gravels it is very difficult to identify bedrock. Recognition of bedrock from drillers' logs in areas of deeply buried and intermediate level buried channel deposits (p. 16-19) is difficult because of the presence of gravel and sand beds or lenses at two or more stratigraphic horizons in one vertical section. Test hole No. 6, for example, encountered gravel and sand at depths of 47 to 65 feet and at 126 to 132 feet. The lower gravel is underlain by soft shale. The upper sand and gravel marks the

contact between till above and buried channel clay and silt below.

Southeastern and southern portions of area

In the area to the south and southeast of the Grimshaw gravels, control on bedrock topography is very poor. Test drilling was not carried out in this area. Drift thickness apparently increases rapidly toward the deeply buried channel near the Peace River. The underlying bedrock is the soft sandstone and shale of the Dunvegan Formation which is very difficult to distinguish as bedrock. The presence of lacustrine silts and sands overlying till, sandy phases within till, and clay phases within the deeply buried channel deposits, makes interpretation of drillers' logs almost impossible. The most reliable control in this area is provided by structure test-hole electric logs through the deeply buried channel in which sand and gravel rests on bedrock at depths of up to 820 feet below ground level. Rare outcrops exposing bedrock or sand and gravel are located on the lower valley walls of the Peace River. To make an accurate drift-bedrock distinction from electric logs of test holes located outside of the area of the buried channel fill is difficult because of the scarcity of reliable marker beds within the Dunvegan Formation and within the drift. However, the contact can be determined approximately in some cases.

Interpretation of Results

The deepest buried channel within the area is adjacent to the present-day Peace River valley. The Research Council of Alberta recently adopted the policy of identifying buried channels with names other than those of nearby rivers, in order to prevent confusion between modern and filled valleys, and because buried channels may cross watersheds and be associated with different modern-day streams in different localities. In accordance with this policy, the deepest buried channel is called the

Shaftesbury Channel and the valley joining it from the north through Cardinal Lake is called the Berwyn Channel. Other smaller channels exist but have not been named. The presence of a major channel which comes to within one mile of the northern edge of the map-area is indicated by a few structure test holes. This channel apparently trends eastward along and adjacent to the Whitemud River. Drainage directions are similar to those of today with the exception of the Berwyn Channel drainage which was southeastwards into the Shaftesbury Channel. Jones (1966) has mapped a buried valley which he calls the Scotswood Channel, approximately 20 miles west of the map-area and lying north of the Peace River. The thalweg lies at between 1,300 and 1,400 feet. This channel may represent a western tributary to the Shaftesbury Channel. The latter crosses the present-day Peace River at a point almost directly south of Whitelaw and to the west of the crossing is located to the south of the Peace River.

The bedrock topography map does not represent topography exactly as it existed prior to ice advance, although it may approximate it fairly closely. Modifications have been made by glacial and post glacial erosion. Just how much modification of the pre-existing land surface was accomplished by glacial processes is not known; the amount of material that was removed is likewise not known.

Buried Channel Deposits

The term "buried channel deposits" is used in this report for deposits of gravel, sand, silt, and clay that directly overlie Cretaceous bedrock and underlie deposits of definite glacial origin. These deposits are alluvial and in some cases, lacustrine materials, laid down in channels or depressions in Cretaceous bedrock.

Previous Investigations

Buried channel deposits have been reported from many places in the Peace River district by various authors. Rutherford (1930, p. 34) mentioned thin layers of gravel resting on bedrock exposed along many rivers in the Peace River country. He interpreted these to be glacial in origin. He also recorded (ibid. p. 33) the presence of a "long ridge" of "boulder clay and gravel" extending from east of Grimshaw west to Fairview which he considered to be glacial in origin and "perhaps a terminal moraine." The portion of this "ridge" extending from east of Grimshaw to just west of Whitelaw, in the present report is considered to be a high-level buried channel deposit herein called the "Grimshaw gravels." Jones (1966, p. 41) favored a preglacial origin for these and other more deeply buried channel deposits. He thought that most of the buried sand and gravel deposits were the probable northern equivalent of the Saskatchewan gravels and sands described by Rutherford (1937) from central and southern Alberta and for which a preglacial* age has been suggested (Rutherford, 1937, p. 81; Warren, 1939, p. 341; Farvolden, 1963, p. 65; Geiger, 1965). Allan and Carr (1946, p. 23) reported possible preglacial gravel and sand from Pinto Creek in township 68, range 10, west 6th meridian. Henderson (1959, p. 64-66) reported deeply buried gravels and sands in the Sturgeon Lake map-area which he termed "Basal gravels" and considered them to be the possible northern equivalent of the Saskatchewan gravels and sands of Rutherford (1937). He stated that they predate the earliest invasion of Laurentide ice into the area and suggested an early Pleistocene age.

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*Defined as "preglacial in the sense that they antedate glaciation from the north and east and lie on bedrock." (Rutherford, 1937, p. 81).

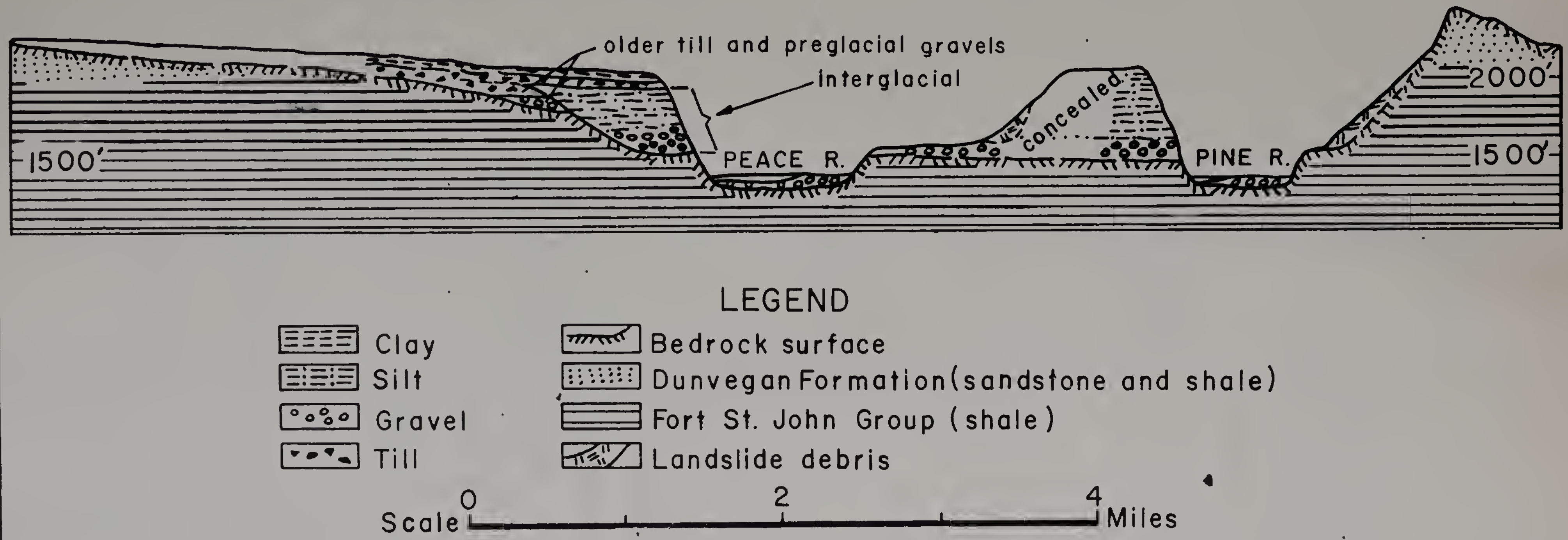
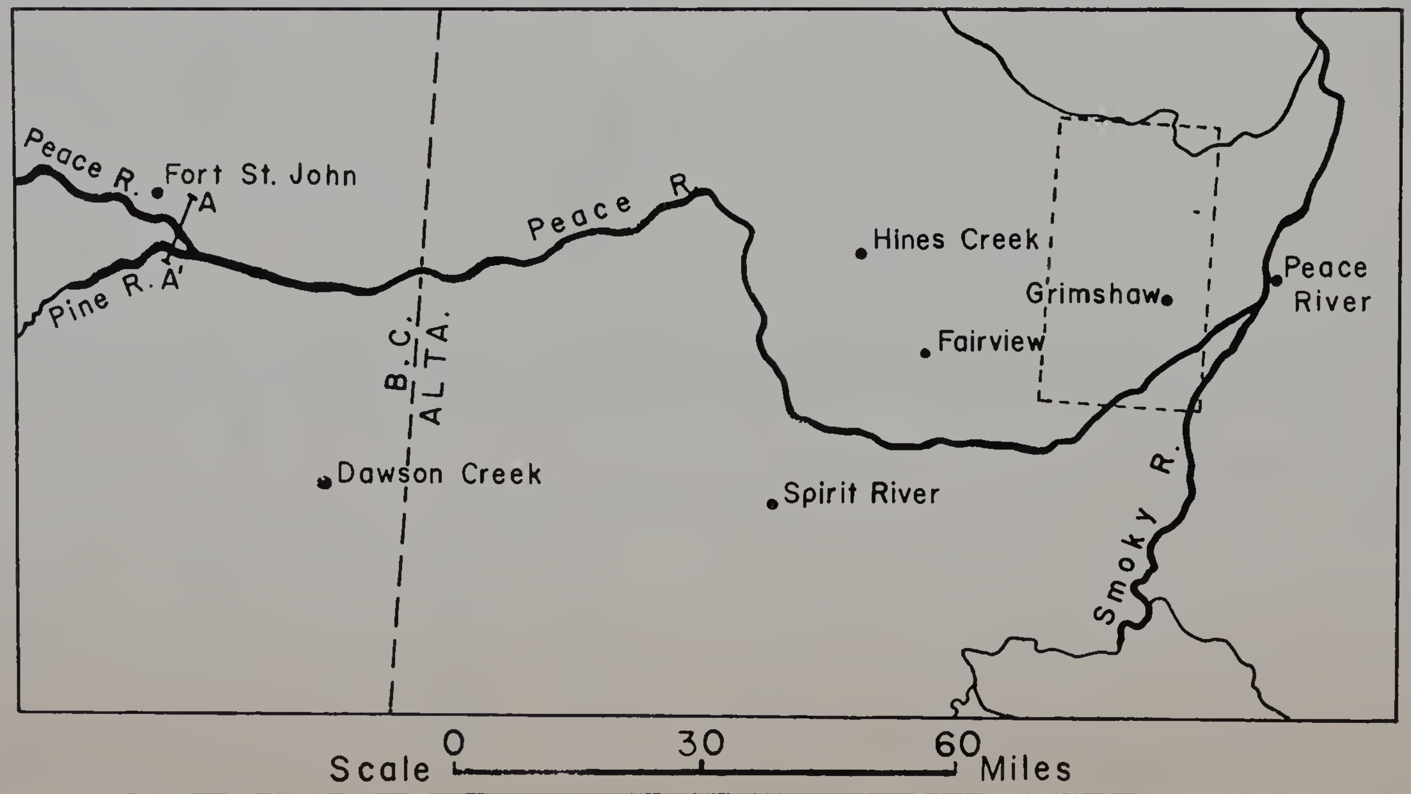


Figure 7 - Geological section across Peace River valley, B. C. (after Mathews, 1963)



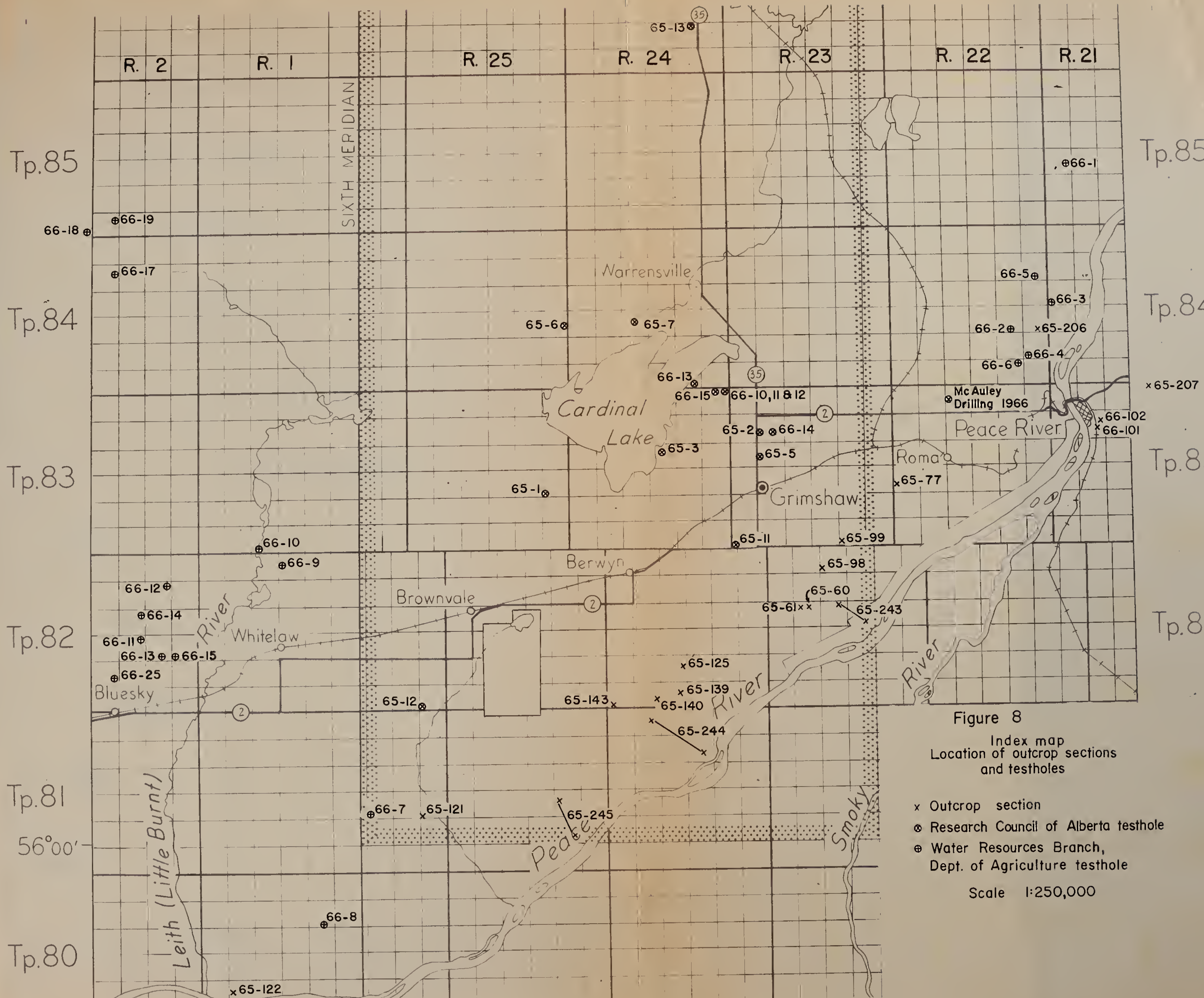


Figure 8

Index map
Location of outcrop sections and testholes

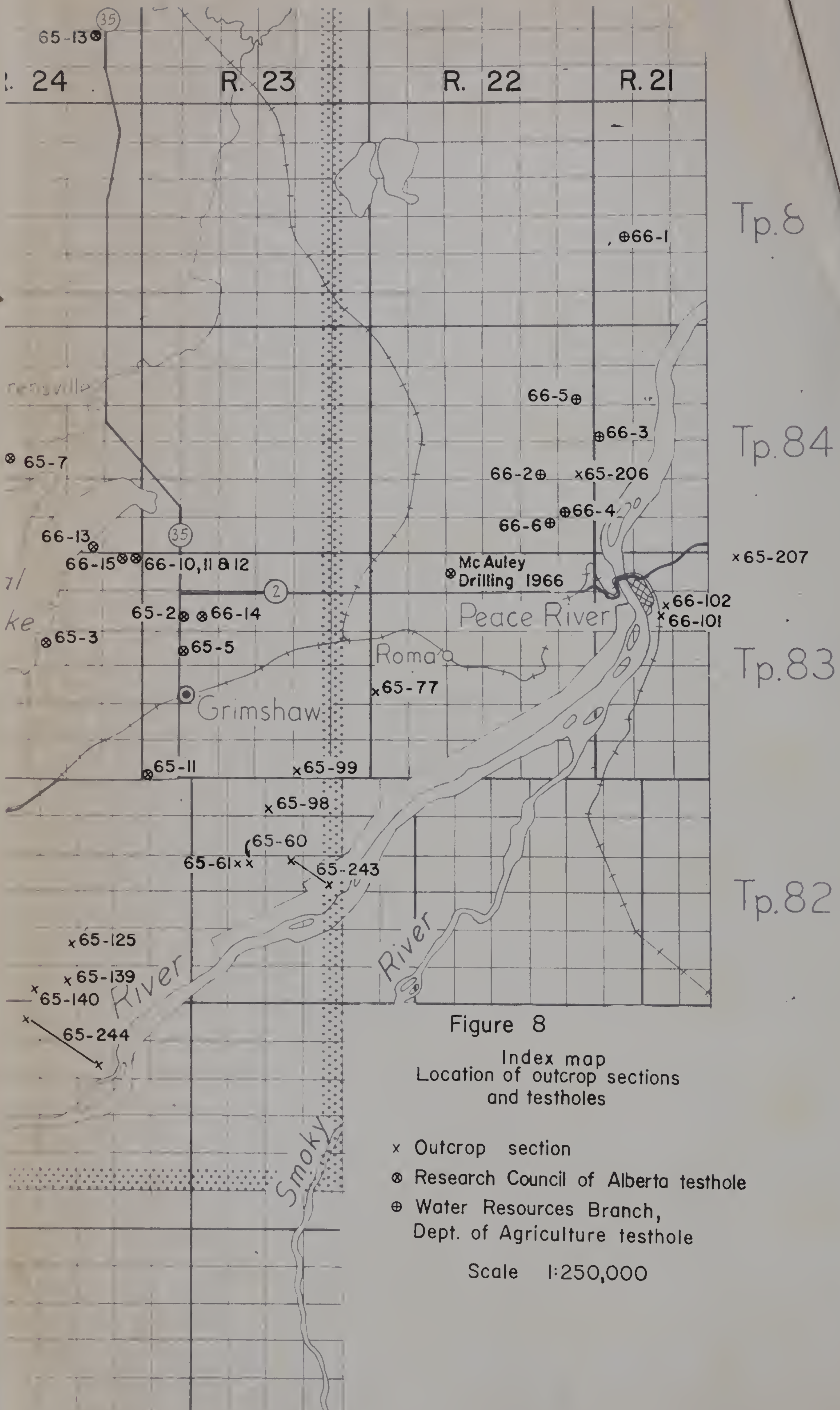


Figure 8

Index map
Location of outcrop sections
and testholes

× Outcrop section
⊗ Research Council of Alberta testhole
⊕ Water Resources Branch,
Dept. of Agriculture testhole

Scale 1:250,000

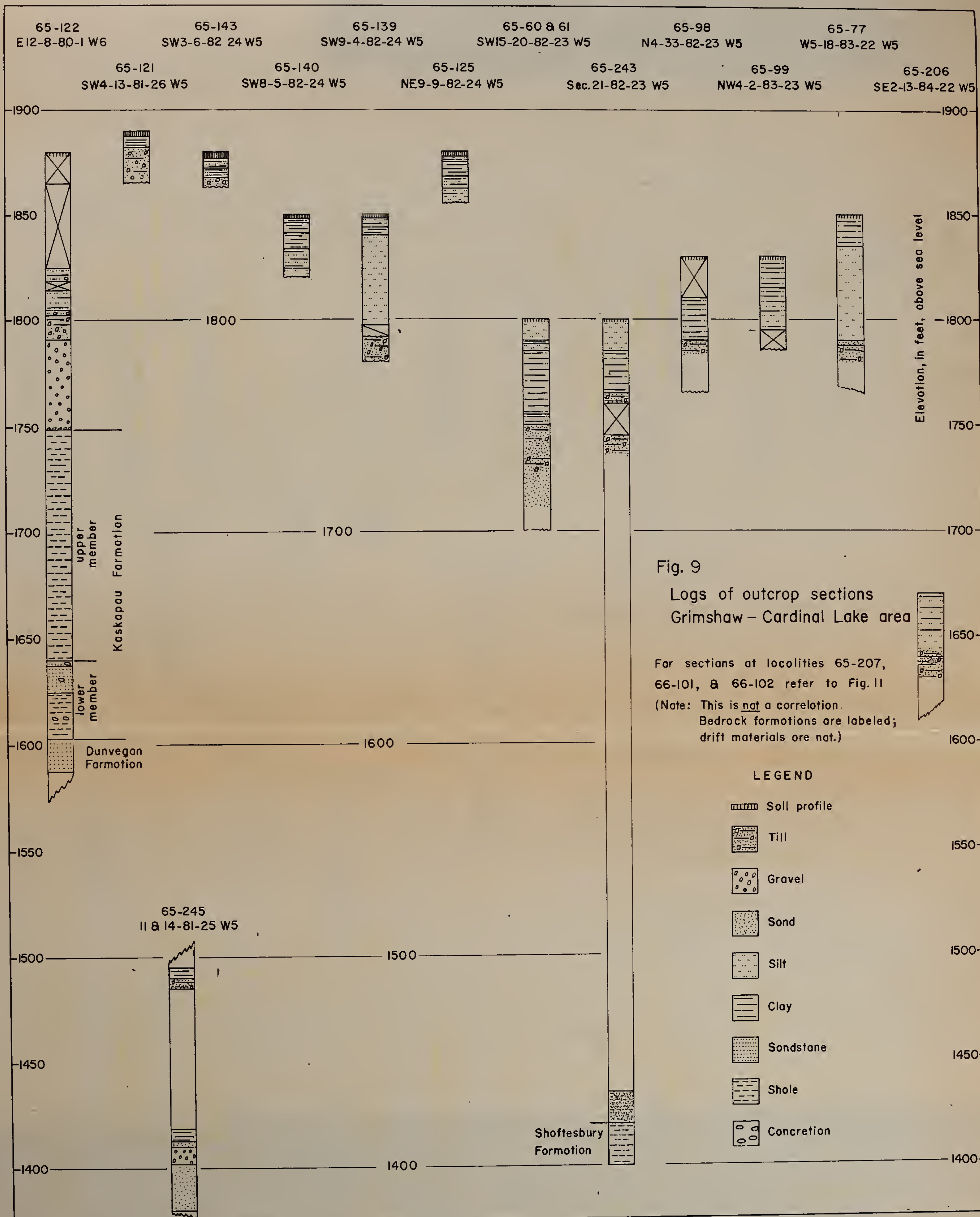
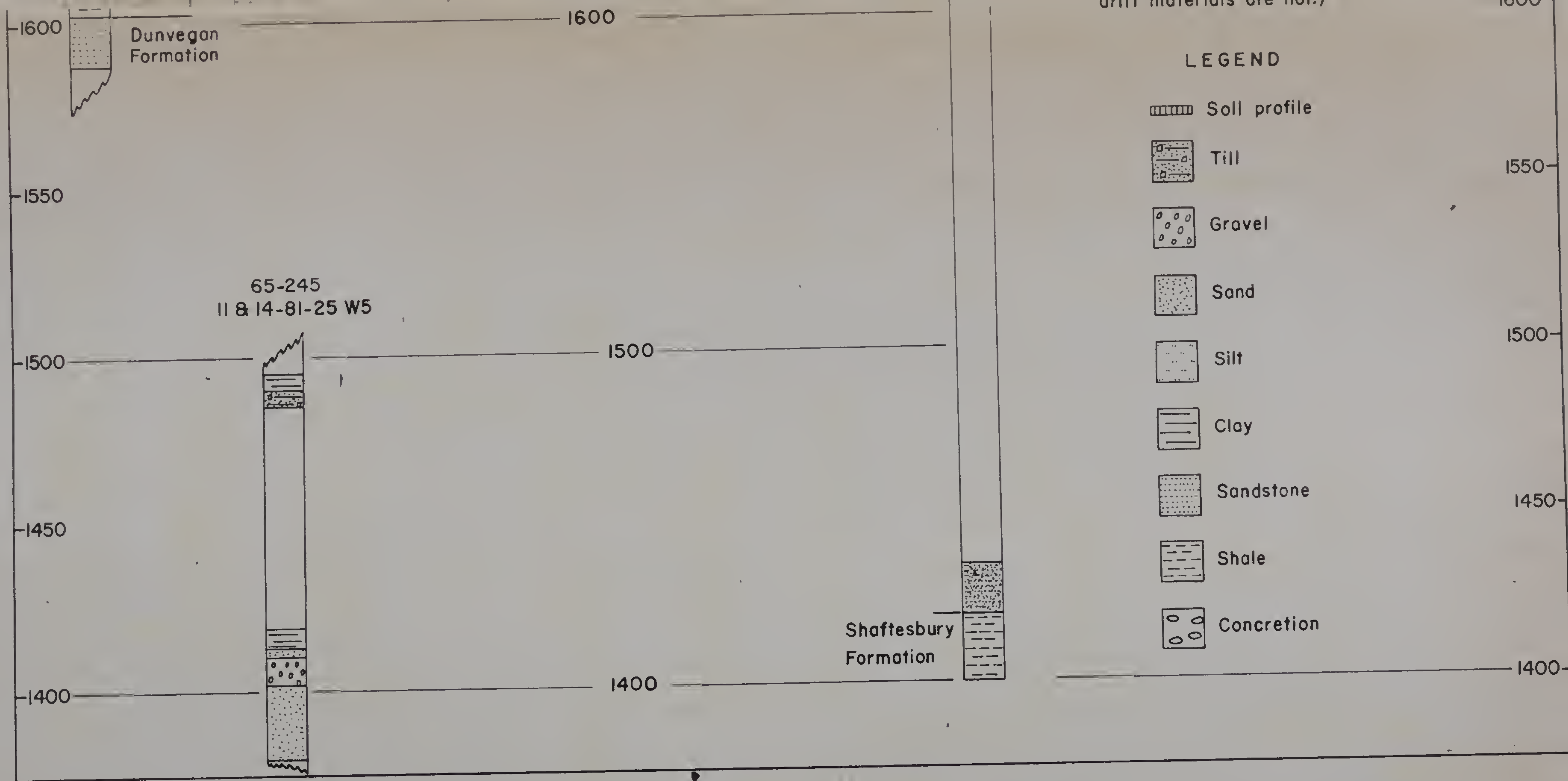


Fig. 9
Logs of outcrop sections
Grimshaw – Cardinal Lake area

For sections at localities 65-207, 66-101, & 66-102 refer to Fig. 11
(Note: This is not a correlation.
Bedrock formations are labeled;
drift materials are not.)



1600
1550
1500
1450
1400
Dunvegan Formation
65-245
11 & 14-81-25 W5
Shaftesbury Formation
LEGEND
Soil profile
Till
Gravel
Sand
Silt
Clay
Sandstone
Shale
Concretion

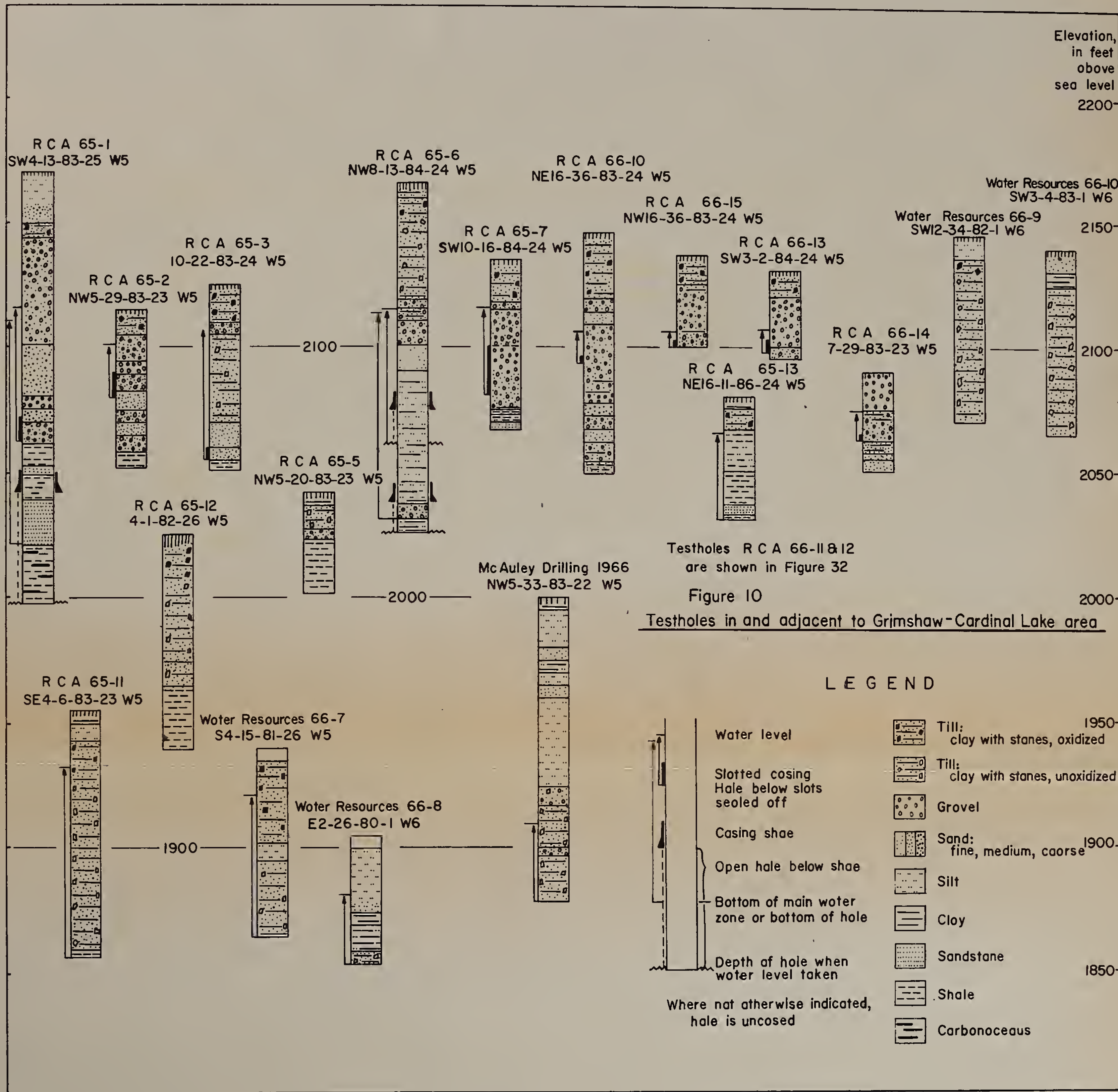
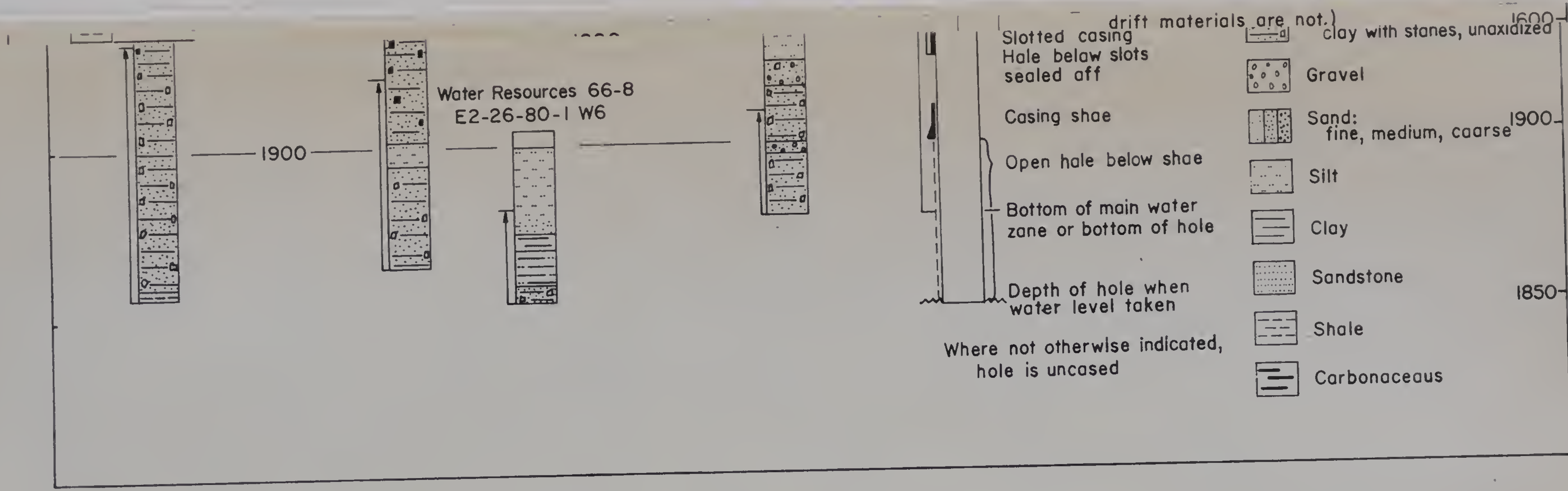


Figure 10

Testholes in and adjacent to Grimshaw-Cardinal Lake area


1900
Water Resources 66-8
E2-26-80-1 W6
drift materials are not.)
Slotted casing
Hole below slots
sealed off
Casing shoe
Open hole below shoe
Bottom of main water
zone or bottom of hole
Depth of hole when
water level taken
Where not otherwise indicated,
hole is uncased
clay with stones, unoxidized
Gravel
Sand:
fine, medium, coarse
Silt
Clay
Sandstone
Shale
Carbonaceous
1900
1850

Mathews (1963, p. 4-7) reported similar deposits exposed along the banks of the Peace River and its tributaries in the Fort St. John area of northeastern British Columbia. He recorded two levels of deposits to which he assigned different ages. In addition to gravel and sand, Mathews recorded great thicknesses of silt and clay within the units, which he termed river and lake deposits. The older, higher-level deposits have their base at 1,750 to 2,000 feet above sea level. Mathews considered these deposits to be early interglacial or preglacial in age. The younger, much thicker unit has its base along the Peace River valley, at 1,500 to 1,600 feet above sea level. The relationship between the two units is shown at one locality (Fig. 7) where a tongue of the younger unit overlies till which in turn overlies the older unit. On this basis Mathews called the younger unit interglacial and early Wisconsin(?) in age. An interglacial age for this unit is supported by pebbles of red granite and gneiss from the gravel at one locality.

Description of Deposits

Buried channel deposits underlie a considerable portion of the map-area. Exposures have been examined in gravel pits, river valley walls, road cuts, and borrow pits. A few test holes have been drilled through the more shallowly buried higher-level deposits (Figs. 8, 9, and 10). The test-hole and outcrop samples provide control in evaluating data on the distribution of these deposits provided by seismic shot-hole drillers' logs and structure test-hole electric logs.

Three major levels of deposits are recognized: (1) deeply buried sand, gravel, silt and clay occupying the Shaftesbury Channel and a major tributary from the south; (2) intermediate level deposits that occupy tributary channels, or

occur as terraces, to the Shaftesbury Channel; and (3) the more shallowly buried higher-level gravels and sands (Grimshaw gravels) which are considered to predate the deeply buried and intermediate level deposits. Terraces at the intermediate level are not extensive or laterally continuous for any distance within the mapped area.

High level deposits (Grimshaw gravels)

The high level deposits are principally gravel and sand. They are here termed the Grimshaw gravels. Numerous exposures of the upper portions of these deposits have been examined in gravel pits, road cuts, and borrow pits. Lower portions are water-saturated and do not crop out. The water table limits the depths of gravel pits and borrow pits. Nine test holes have been drilled into the deposits, five of which were drilled through them into underlying bedrock. Additional information on the distribution, thickness, and gross lithology is provided by seismic shot-hole drillers' logs, water-well logs, and structure test-hole electric logs.

Thicknesses of 43 to 85 feet have been determined in test holes drilled by the Research Council along the main trend of the deposits. Greater thicknesses have been obtained in seismic shot holes (Encl. 2).

The deposits consist mainly of fine, pebble-sized, well-sorted, well-rounded gravel with interbedded sand (Plate IB). The pebbles making up the gravel are mainly quartzite, chert, and vein quartz, although granitic, volcanic, and low-grade metamorphic rocks, all of western Cordilleran derivation, make up nearly 10% of the pebbles. Glacially-derived rock types typical of the Canadian Shield* have not been found. A pebble count of all pebbles larger than 0.2" (5.08 mm) was made on gravel taken from a borrow pit in the southwest quarter, Sec . 25, Tp. 83,

*Rock types typical of the Canadian Shield include igneous and metamorphic rocks. High-grade metamorphic rock types are abundant. Dark coloured granitic gneisses are common. Igneous rocks of many types are present. Rock types of western Cordilleran derivation also include igneous and metamorphic varieties but these differ from the Shield-type rocks (see Table 2) in that gneisses are not present, the metamorphic rocks are low grade, and the igneous rocks are light-colored acidic varieties which are quite distinctive.

R. 24, W. 5th Mer. The results are shown in table 2.

All the rock types are well rounded and often slightly flattened in shape. Some of the metamorphic schistose varieties are well rounded and elongated (cigar shaped). Some of the fine-grained unidentified pebbles are likely volcanic. If the questionable pebbles, which are most likely volcanic, are included, the totals of volcanic and granitic varieties are in the order of 5 and 2% respectively. Of all the pebble types the granitic varieties show the greatest degree of weathering.

The sand portions of the deposits are well sorted to poorly sorted (Fig. 12)* and are everywhere noticeably micaceous, the mica being the muscovite variety. The muscovite is probably derived in large part from the breaking down of the highly micaceous granitic pebbles.

The sands and gravels range from horizontally bedded to strongly cross-bedded. Cut and fill structures are present (Plate IB). Directions of crossbedding were measured at a number of localities (Fig. 13). The directions obtained are not consistent, which could perhaps be expected in a fluvial environment. A current direction to the northeast, parallel to the subsurface trend of the Grimshaw gravels, to the buried Shaftesbury Channel (Encl. 4) and to the present-day Peace River can reasonably well be assumed.

The overlying drift cover is mainly till and local glaciofluvial materials. It can be as much as 40 feet thick and is rarely less than 5 feet thick.

The bedrock topography map (Encl. 4) and the geologic cross sections (Encl. 4 and Fig. 14) indicate that the base of the Grimshaw gravels lie mainly in the interval between 2,050 to 2,100 feet in elevation, or approximately 1,000 feet higher than the lowest elevations at which the deeply buried deposits occur.

* see Appendix III for a discussion of grain size parameters.

Table 2. Pebble types in Grimshaw gravels
SW 1/4, Sec. 25, Tp. 82, R. 24, W. 5th Mer.

Pebble type	Number of pebbles	Per Cent of total
Quartzite varieties, mainly light colors	513	40.3
Chert varieties, mainly black chert	330	25.9
Vein quartz	257	20.2
Volcanic varieties (purple, green, and brown colors dominant)	51	4.0
Granitic igneous varieties, mainly whitish muscovite-rich rocks	18	1.4
Low grade metamorphic varieties; micaceous schistose rocks and banded argillites	16	1.3
Unidentified, mainly fine grained; predominantly sedimentary, some volcanic	73	5.7
Unidentified, igneous or volcanic	13	1.0
Ironstone, angular, locally derived	1	tr
Total	1,272	99.8

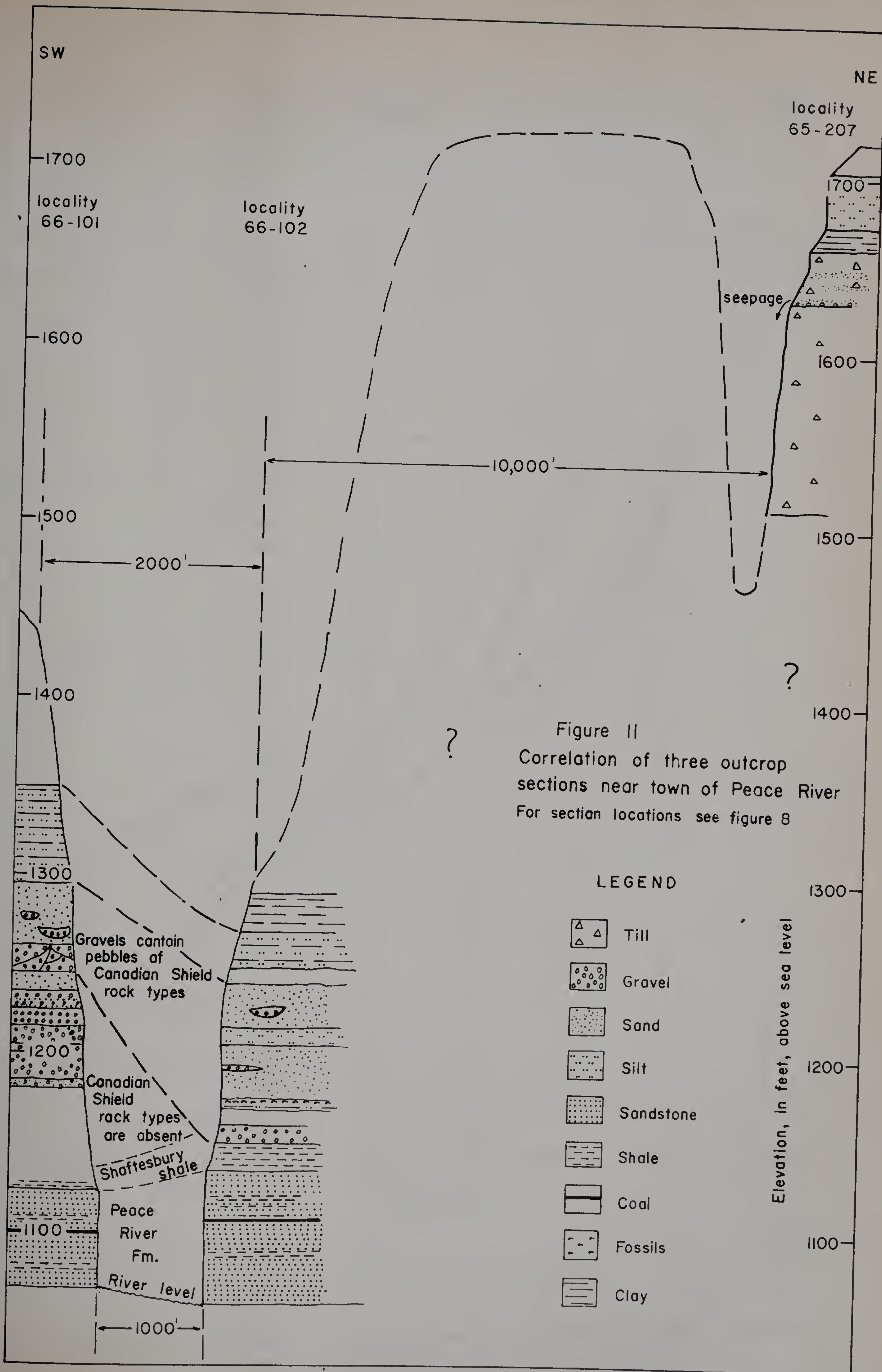


Figure 11
Correlation of three outcrop sections near town of Peace River
For section locations see figure 8

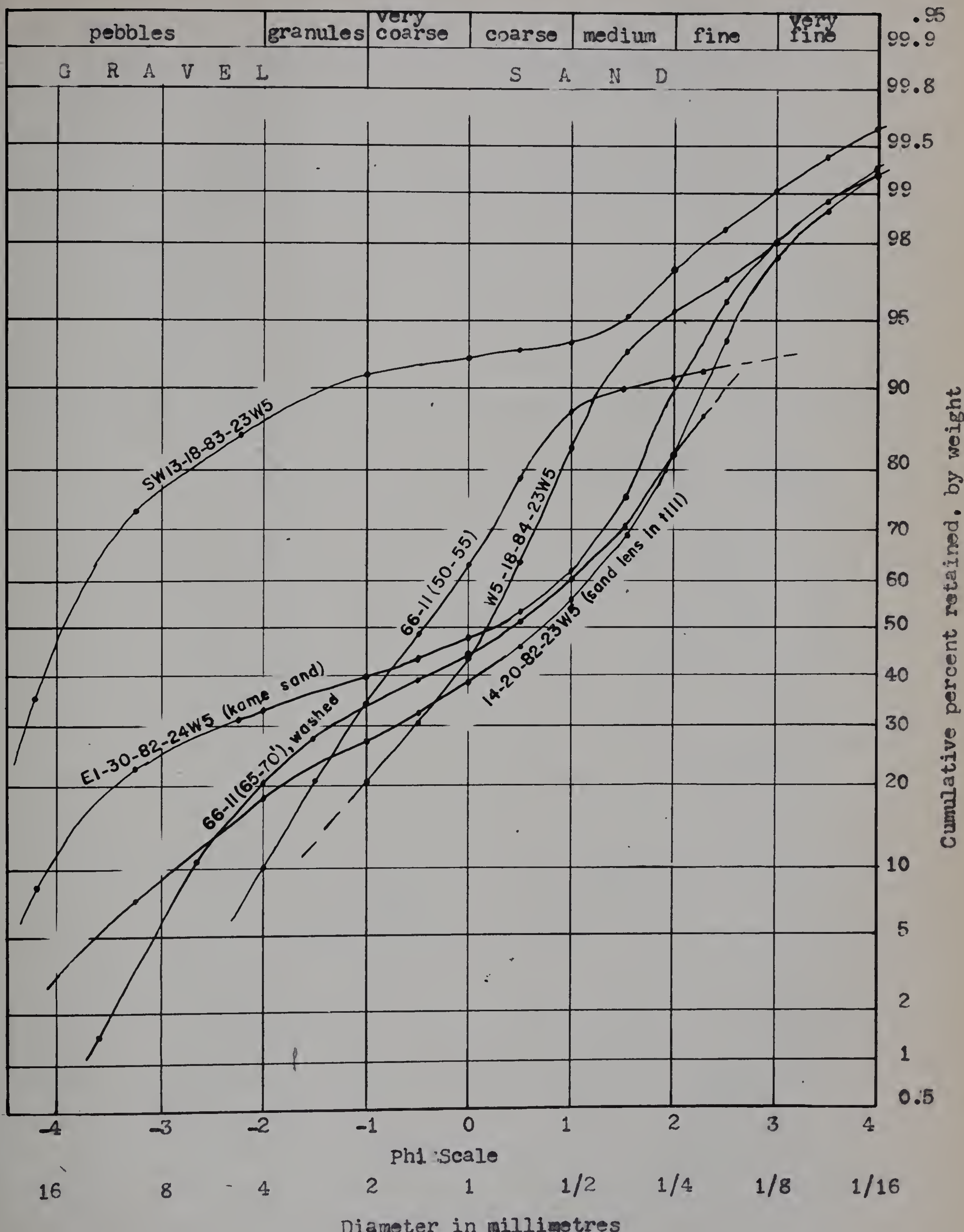


Figure 12 - Grain size analyses of selected samples, sands and gravels.

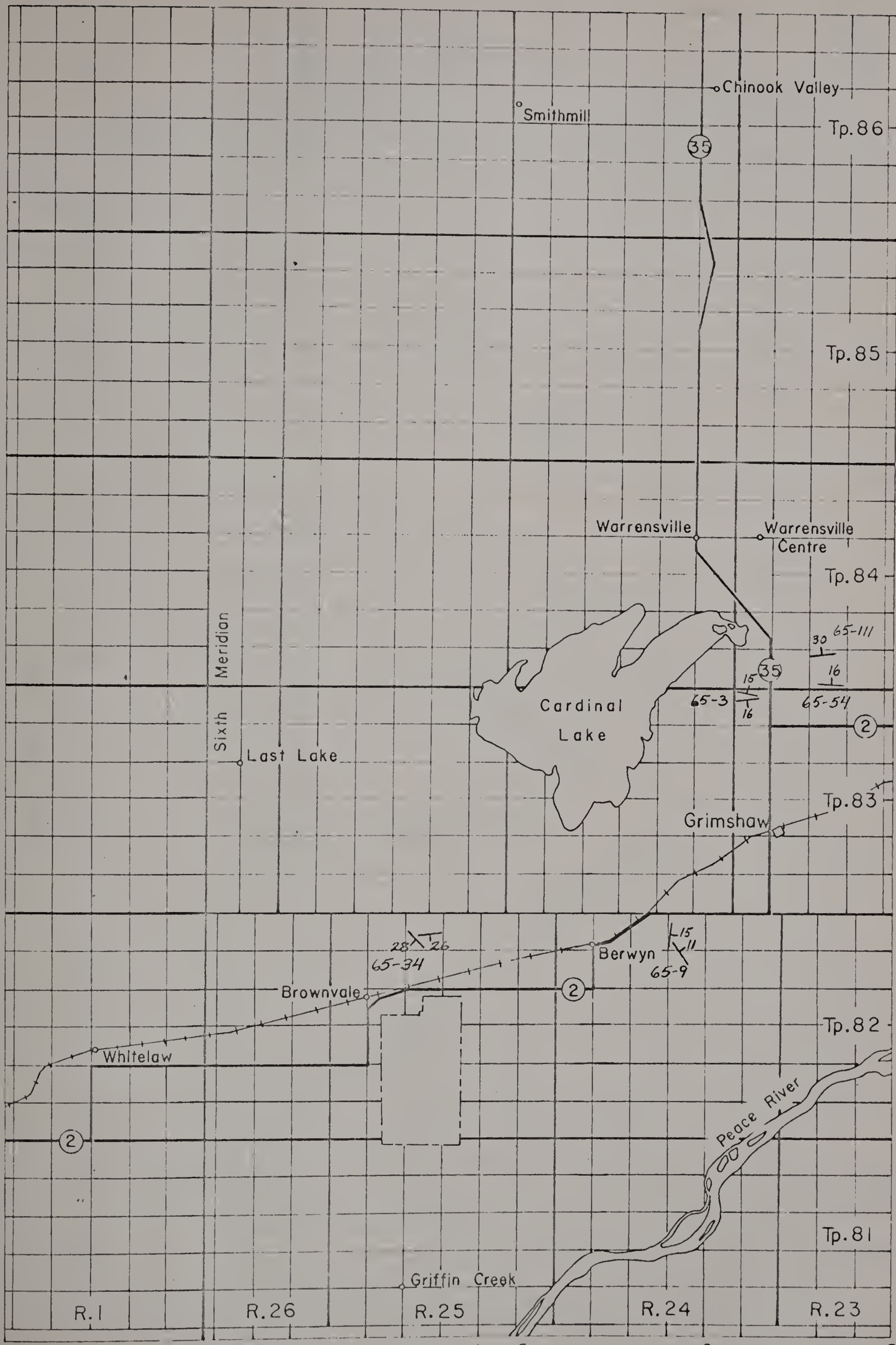


Figure 13- Cross bedding directions in Grimshaw gravels.

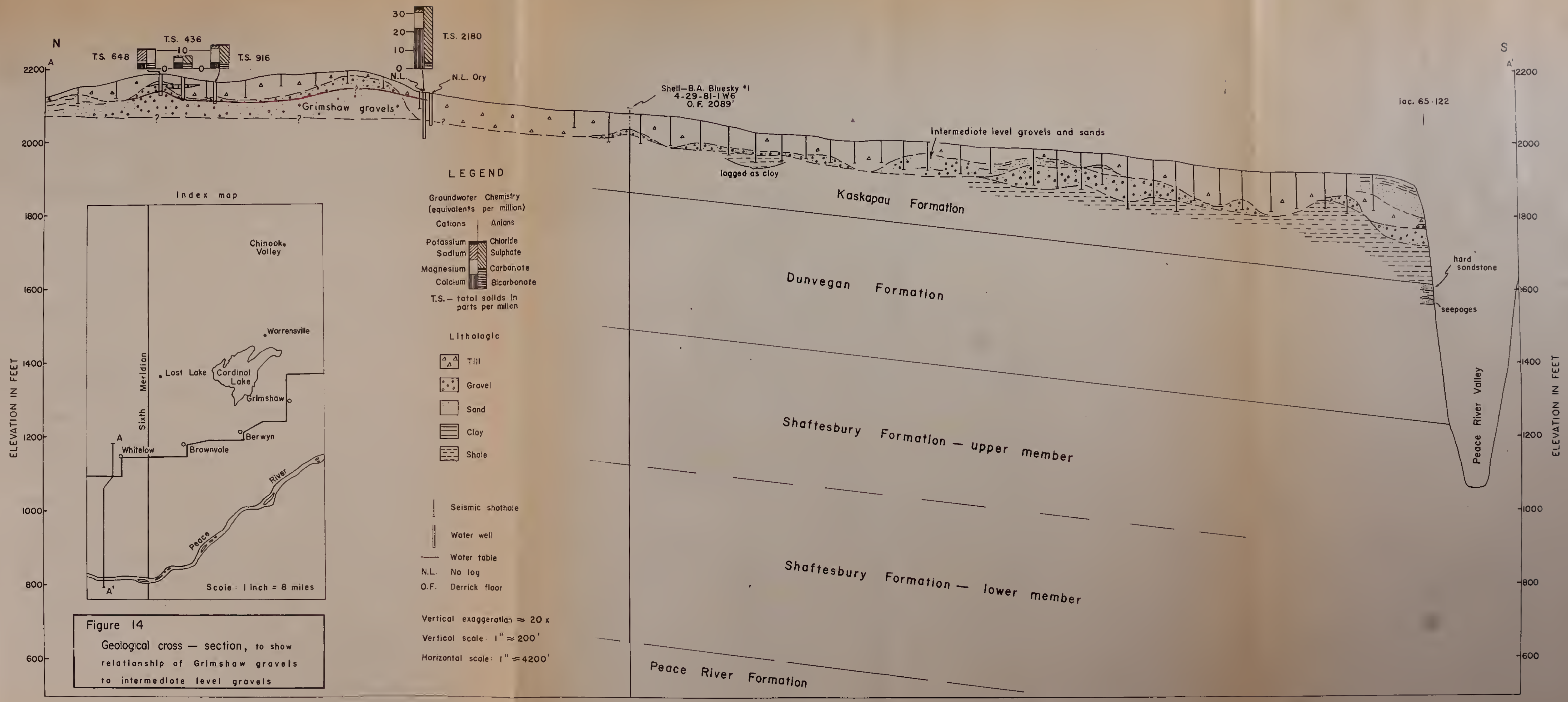
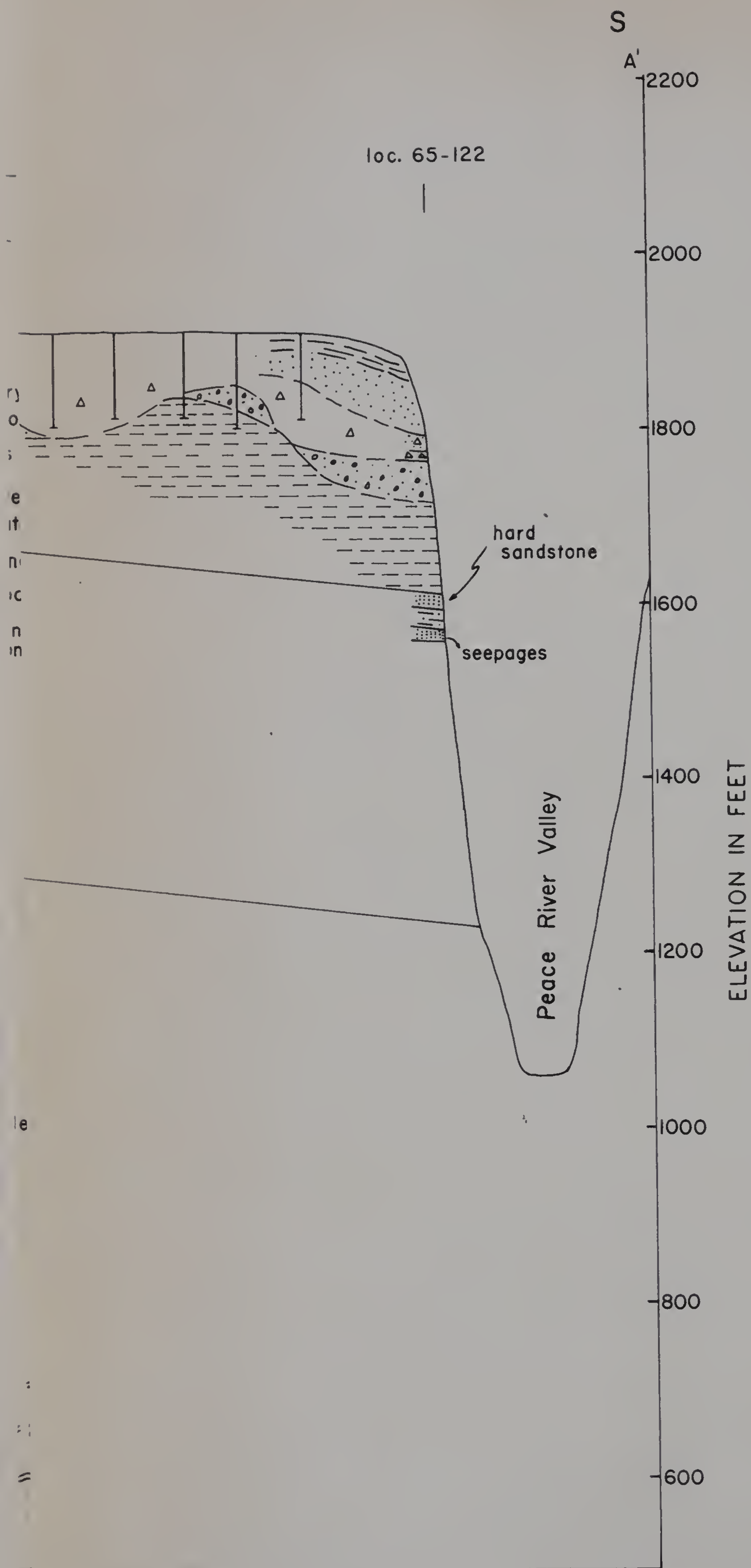


Figure 14
Geological cross — section, to show relationship of Grimshaw gravels to intermediate level gravels



S
A'
loc. 65-122
hard sandstone
seepages
Peace River Valley
2200
2000
1800
1600
1400
1200
1000
800
600
ELEVATION IN FEET

The Grimshaw gravels are interpreted as representing a much earlier phase of river deposition than the lower deeply buried gravels of the Shaftesbury Channel. Both probably were deposited by the same river system. In effect, the Grimshaw gravels form a high level terrace of the younger deeply buried river valley. The continuity of the Grimshaw gravels is broken by channels formed by later streams (Encl. 2) and now occupied by channel fill. Seismic shot hole and structure test hole control indicates that the Grimshaw gravels are not present, except very locally, to the west of the mapped area for at least 20 miles (the limit of checking), or to the north for at least 10 miles. Later stream erosion has removed these deposits in these directions. Gravel deposits of the same age as the Grimshaw gravels are to be expected in other areas of the Peace River district. A broad plain at an elevation of about 2400 feet in the Cherry Point area of Alberta, some 60 miles to the west of the map-area is reported to be underlain by gravels (C.R. Stelck, pers. comm.) which may be the western equivalent of the Grimshaw gravels.

Intermediate levels of sand and gravel

Deposits of sand and gravel at intermediate levels between the high terrace level and the deep buried valley are only sporadically distributed within the map-area and occur at fairly high levels. Deposits at intermediate levels occur at three main localities: 1) on the northwest side of Cardinal Lake; 2) within Cardinal Lake; and 3) in a narrow belt running from Grimshaw southwestward to the southwestern corner of the map-area. The deposits of the first two localities are within the buried Berwyn Channel. Deposits of the last locality probably represent a mixture of both terrace deposits bordering the Shaftesbury Channel and of tributary channel deposits.

Four miles west of the map-area, gravel deposits extend almost continuously from about 2,060 feet in elevation down to about 1,720 feet in elevation (elevations taken at the base of the deposits) over a distance of about 5 miles (Fig. 14). A section measured at the lower elevation (section at locality 65-122) contains 44 feet of gravel of composition

similar to that of the Grimshaw gravels. This is overlain by till or reworked till containing lenses of silt and clay.

Deeply buried deposits

Outcrops of the deeply buried deposits are scarce because of large-scale slumping along present-day river valley walls. The slumping is widespread where the valley walls are cut in the loosely consolidated deposits of thick surficial sequences. Consequently, where outcrops of the deeply buried deposits might be expected, slumping has been common and sections are at best poor. Where isolated exposures occur, it is difficult to determine if the material is in place or has slumped from above.

Only three exposures of these materials have been examined, two of which are located 9 miles east of the map-area near the town of Peace River. These two are particularly good sections, while the exposure within the map-area is a short section from near the upper part of the deposits. The section locations are shown in figure 8 and the sections described in Appendix 1. They are discussed briefly below.

A tentative correlation between the sections at localities 66-101 and 66-102 (Plate IA) near Peace River town is shown in figure 11 and these are correlated with the section at locality 65-207 which is stratigraphically and topographically higher. The base of the gravels at locality 66-102 lies at approximately 1,150 feet elevation. These gravels are composed predominantly of well-rounded, mainly quartzite pebbles but contain a few gneissic and granitic pebbles typical of the Canadian Shield. A two-foot massive clay unit which lies 21 feet above the base of the gravel contains squashed and comminuted shells of small snails and ostracods. This is overlain by a resistant unit of hard-packed silt and fine sand in which layers of gravel are found; the pebbles of the gravel are predominantly poorly sorted and angular and consist largely of igneous and high-grade metamorphic rocks typical of the Canadian Shield. The section culminates with 24 feet of unctuous*

* having a greasy, or soapy feel when rubbed or touched with the fingers.

platy clay. The total exposed thickness from the base of the lower gravel unit to the top of the platy clay is 141 feet. Till is lacking in the exposed parts of the section.

The section at locality 66-101 is located approximately 1,000 feet south of the section just described, on the opposite side of the Heart River. The base of the channel deposits is not exposed in this section but lies somewhere within a covered interval extending from about 1,130 to 1,80 feet above sea level.

Above the covered interval mainly gravel, grading upwards to mainly sand at the top, is exposed for 65 feet. The gravel is composed mostly of well-rounded quartzite and chert pebbles and contains numerous pebbles of Cordilleran-type igneous, volcanic and metamorphic rocks. No Shield-type rocks were noticed, and a pebble count of 457 pebbles from the interval 113 to 133 feet from the bottom of the section disclosed no Shield-type rocks. The gravel and sand unit is overlain by 16 feet of gravel containing some Shield-type pebbles, and this in turn is overlain by 36 feet of sand and 55 feet of silt and sand interlaminated with clay, for a total thickness of about 260 feet.

The exposures at locality 65-245 (Secs. 11 and 14, Tp. 81, R. 25, W. 5th Mer.) crop out along a road leading down to the Peace River. A 126 foot interval was measured, of which two-thirds is covered by slump deposits. The base of the exposed section is at approximately 1,380 feet in elevation. The lower part consists of 33 feet of mainly sand with some gravel. The pebbles in the gravel are predominantly quartzite, probably of Cordilleran derivation. Volcanic, igneous, and low-grade metamorphic rocks of Cordilleran type are also represented. Locally derived ironstone and soft platy sandstones are present, but no Shield-type rocks were noticed. This sand interval is overlain by 5 feet of gritty clay, platy clay, and poorly bedded till-like clay with stones. A covered interval of 82 feet overlies this, followed by 10 feet of layered clay and sand with gravelly lenses

which contain numerous Shield-type pebbles. The relationship of this section to other deposits is shown in the geological cross section (Encl. 4). A nearby structure test hole indicates that the base of the channel in this vicinity is at approximately 1,160 feet above sea level and that the measured section lies near the top of a section of buried channel deposits 350 feet or more thick.

Additional control on these deposits is provided by structure test-hole electric logs. The base of the channel is easily picked from the logs, as the basal sands and gravels are expressed as strong deflections of the traces on the electric logs. The contact with the overlying till is not clearly defined; consequently, it is difficult to obtain a thickness for the channel deposits. The electric logs indicate that these deposits occur at elevations as low as 1,070 feet above sea level.

Radio-carbon dates indicating a minimum age of 35,000 years B.P. (J. Westgate and R. Green, personal communication) have been obtained by the Research Council of Alberta from peat and wood lying within a channel deposit located 20 miles south of the map-area near the town of Watino. This age is tentative only. Check samples have been submitted to corroborate the age obtained. The gravel-bedrock contact in this section lies at an approximate elevation of 1,250 feet above sea level and the peat and wood are found about 15 to 45 feet above the contact. Gravels with abundant pebbles composed of rock types common to the Canadian Shield occur approximately 115 feet above the contact.

From the foregoing, it can be concluded that:

1) The buried channel deposits can attain great thicknesses.

2) Glacially derived Shield-type pebbles are not uncommon in the upper portions of the deposits at least.

3) Sands and gravels containing glacially derived pebbles directly overlie deposits which do not contain glacially derived pebbles.

4) The lower deposits may be 35,000 years old (Mid-Wisconsin) or older.

Glacial Deposits

Glacial deposits and land forms may be divided into three categories:

1) till

2) glaciofluvial deposits and features

3) glacial lacustrine deposits and features

Results of carbonate and grain-size analyses of various surficial materials are given in the appendix.

Areas of Till

Flint (1957, p. 109) stated: "We regard till as glacial drift dominantly nonsorted according to grain size. It is the non-size-sorted end member of a series whose opposite end member is well-size-sorted stratified drift. Ideally till is formed without the cooperation of water, but actually size sorting is present to an indefinite degree in deposits to which the term is applied." According to this definition, till can include some sorted materials. Most of the areas mapped as till (Encl. 1) show pockets and stringers of poor to well sorted materials, but

unsorted till is dominant.

Two types of till are present in the map-area, representing lithofacies of one till sheet. These are: a northern till containing rocks of Canadian Shield origin and locally derived rocks from the underlying Dunvegan Formation and Smoky River Group, and a southern till in which locally derived, rounded stones of the underlying Grimshaw gravels predominate. The two tills are time-equivalent, the difference in pebble composition being due to different local source materials. Both are quite clayey,* as evidenced by the general description given to them by farmers when describing the formations encountered during the digging of a well as "clay" or "clay with small stones." Shot-hole drillers call it "clay" or "clay and rocks."

The northern type of till covers the flanks and top of the Whitemud Hills. The till cover is thin over the hills themselves (about 5 to 25 feet thick). Prominent glacial flutings in a direction slightly west of south show up well on aerial photographs. Till cover on the flanks of the hills attains thicknesses of over 60 feet. Lineations in a southwest-northeast direction which probably represent directions of glacial movement are evident from aerial photographs off the north and south flanks of the hills. The till surface is usually topographically fairly flat and relatively featureless. It may be classed as ground moraine. Near the eastern edge of the map-area in Tp. 85, R. 23 (Secs. 2 to 4, 9 to 11) there is a small area of east-west trending till ridges which may be called washboard moraine or ridged moraine (after Greer and Christiansen, 1963).

The southern type of till occurs south, east, and west of Cardinal Lake (Encl. 1). It is underlain over more than 90% of its exposed area by the Grimshaw

* Refer to fig. 39 (grain size analyses of < 2 mm. fraction of tills) and to Appendix III.

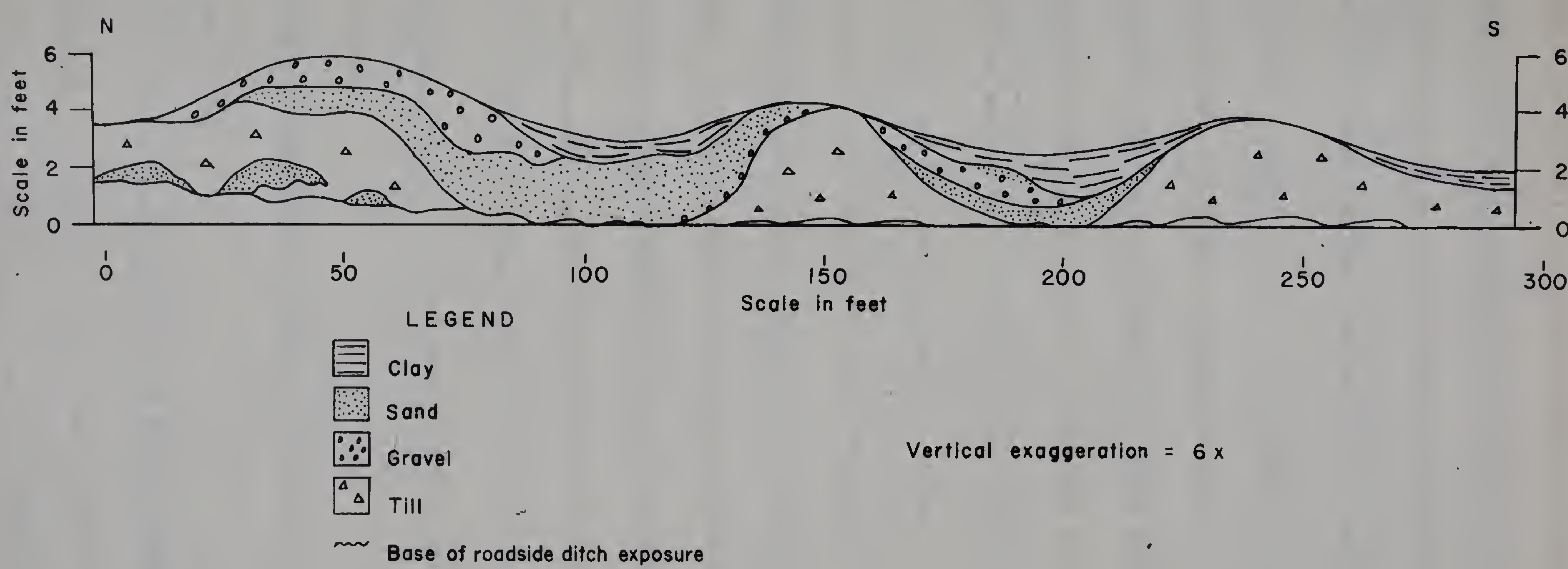


Figure 15 - Field sketch to show stratigraphic relationships in area of subdued hummocky topography within area of southern till. Locality 65-221, lsd. 4, sec. 13, twp. 83, rge. 25 W5th Mer.

gravels from which the till derives the bulk of its content of stones. In most places the till is less than 30 feet thick. It has been mapped as ground moraine; the topographic expression varies from gently undulating to rolling. There is evidence that this till has been subjected to water-washing and reworking over most or all of its exposed area, and where possible the features and deposits formed as a result of this activity have been mapped. Some of the features that indicate fluvial and wave activity are listed below and are discussed more fully in following sections.

1) Large sandy "kames" are present just north and south of Berwyn.
2) A broad belt with a thick cover of silt and sand extends north-northeast from Brownvale to Cardinal Lake. The hummocky topography of this belt suggests deposition on dead ice.
3) Local areas of subdued hummocky topography occur on either side of the belt just mentioned. Sand, with lesser amounts of clay and gravel, is found between hummocks and overlying hummocks, and sand lenses are found within the till of the hummocks (Fig. 15).
4) Discontinuous lines of thin sand and gravel occur at elevations of about 2,200 feet. These appear to be remnant beaches and suggest inundation of most or all of the till area at an early stage of glacial retreat.
5) Meltwater channels are present in both the southern and northern areas of till.

Drumlins and drumlinoid features are locally common in the areas underlain by thin glacial till. Drumlins in shale of the Kaskapau Formation and in sandstone and shale of the Dunvegan Formation are well developed on the eastern end

of the Whitemud Hills. The drumlins trend in the same direction as the glacial flutings across the crest of the Whitemud Hills. Drumlins or drumlinoid features are also developed on Grimshaw gravels. The most prominent of these is one approximately five miles long and one-half mile wide which trends southeasterly into Cardinal Lake. Till cover is thin to absent over these features, although the tail end of one, at least, is dominantly till (Sec. 30, Tp. 83, R. 23, W. 5th Mer.).

Glaciofluvial Deposits and Features

Some of these have been mentioned in the previous section and are discussed here in more detail. They include the "kames" north and south of Berwyn, the belt of silt and hummocky sand northeast of Brownvale, and the meltwater channel systems throughout the area.

Holmes (1947, p. 248) defined a kame as "a mound composed chiefly of gravel or sand, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposit accumulated." Gradations from isolated symmetrical kames to compound kames and kame-complexes can be found. He further stated (p. 248) that "... flat-topped kames, as part of a kame-complex, may grade into an outwash plain."

The isolated hillocks north and south of Berwyn shown on the accompanying map (Encl. 1) are interpreted as kames. The kame south of Berwyn is a smoothly-rounded hillock from 8 to 20 feet higher than the surrounding till plain. (The topographic contour through the hill taken from the 1:50,000 National Topographic Series map is in error. This has been checked by surveyed seismic shot-hole elevations, elevations along the highway profile, and by casual observation.) The material making up the kame is poorly sorted sand* with some gravelly

* Refer to fig. 12 and to Appendix III

streaks. Bedding could not be determined in the limited exposures available. The rounding of the hill was probably accomplished by slumping and by wave action of a glacial lake (Lake Falher, see p. 31). A water well drilled near the crest of the hill encountered 28 feet of sand overlying "blue clay" (driller's description).

The kame to the north of Berwyn is 35 to 40 feet higher than the till ridge which runs north from it. The topography across the kame hill is rough and hummocky. Fine, fairly well sorted sand makes up the kame. Bedding could not be determined.

The belt of silt and hummocky sand located northeast of Brownvale varies from topographically high (where strongly hummocky) to topographically low (where less noticeably hummocky). Well developed kettle holes are found locally in the topographically low areas. Sand lenses are found within till near the edges of the belt of silt and sand (Fig. 15). It is suggested that the sand lenses within the till were laid down by meltwater in crevasses in dead ice. Later slumping of ablation till into the crevasses covered the sand. This is the same mechanism suggested by Gravenor and Bayrock (1956) in the filling of stream trenches in east-central Alberta. The deposition of gravel, sand, and clay between and overlying the hummocks was probably accomplished when melting of the stagnant ice was nearly complete.

A conspicuous ice-marginal meltwater channel occurs on the northern side of Whitemud Hills. Less prominent channels occur across the eastern end of these hills and near and approximately parallel to Cardinal Creek. Another channel system is found northeast of Last Lake (Tp. 84, R. 26, W. 5th Mer.), another east

of Brownvale (Tp. 82, R. 25, W. 5th Mer.), and still another 2 to 4 miles west of Brownvale (Tp. 82, R. 26, W. 5th Mer.). These latter channels represent spillways of glacial lakes, as will be discussed later.

Glacial Lacustrine Deposits and Features

A glacial lake is defined as a standing body of glacial meltwater. This is a general term which includes superglacial, englacial, subglacial, impounded, proglacial, and ice-marginal lakes. The lakes discussed below were probably mainly ice-marginal in their early stages at least, in some cases becoming proglacial (not in contact with the ice) in their later stages. Because of this composite history, the general term "glacial lacustrine" is used here. Three main areas of glacial lacustrine deposits have been differentiated. These are:

1) lacustrine deposits adjacent to the Peace River (deposits of glacial Lake Falher)
2) lacustrine deposits adjacent to Cardinal Lake (deposits of glacial Lake Cardinal)
3) lacustrine deposits adjacent to Whitemud River (deposits of glacial Lake Whitemud).

The first two areas exhibit well marked frontal beaches (Plates II and IIIA) and backshore deposits. The back shore deposits are characterized by poorly defined strand lines, thin discontinuous deposits of sand and gravel, and patches of clay overlying till.

The lacustrine deposits adjacent to the present-day Peace River were considered by Taylor (1958, 1960) to be deposits of a large Pleistocene lake which

he called "Lake Peace" and which extended from the foothills of British Columbia east to Lesser Slave Lake and north into the Northwest Territories. "Lake Peace," however, is a composite of several glacial lakes which existed at different times as the ice front retreated to the north and northeast. A prominent beach ridge at 2,000 feet elevation marks the northeastern edge of the lake sediments over most of the Grimshaw area. Poorly defined strand lines and discontinuous sand and gravel overlying till extend to elevations in excess of 2,100 feet. These correlate with shorelines and poorly developed beaches at 2,000 feet elevation of glacial Lake Falher (Henderson, 1959, p. 75). Thus, the lacustrine deposits adjacent to the Peace River in the Grimshaw area are considered to have been laid down during Lake Falher time and probably represent deposition during the last, Lake Falher III, stage of this lake (Henderson, 1959, p. 76-77). Well developed strand lines near Fairview, approximately 15 miles due west of the map-area, lie at elevations of from 2,170 to 2,200 feet. These probably represent a higher and earlier stand of glacial Lake Falher.

Several high beaches are well developed west and southwest of Brownvale at elevations from about 2,120 feet to 2,195 feet. Two of the most prominent of these lie at elevations of approximately 2,145 and 2,155 feet (Plate II) and extend continuously for at least two miles. These may represent high stands of Lake Falher in its early stages or of some earlier lake. When the level of Lake Falher dropped to the 2,000-foot shoreline level this lake would no longer exist. A meltwater channel system with bottom elevations of less than 2,150 feet leads from Leith (Little Burnt) River north of Whitelaw and west of the map-area into the lake basin associated with these beaches. A thin cover of clay or silt and clay overlies till over most of the lake basin. In the northeast corner of Sec. 11,

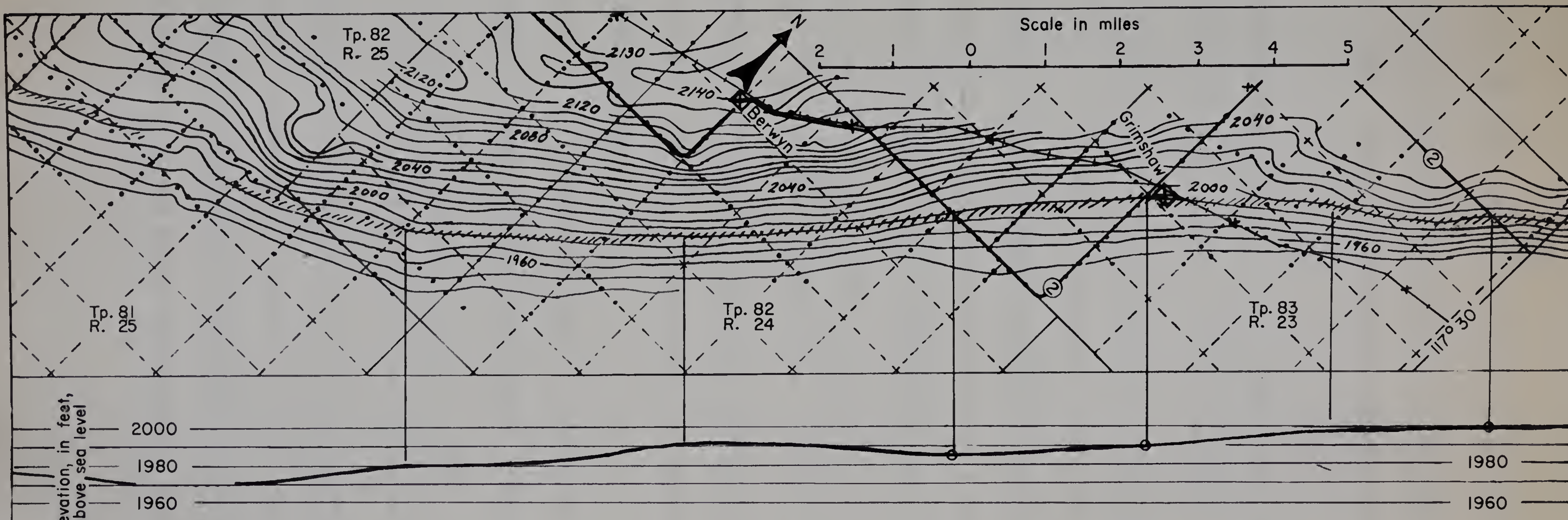


Figure 16
Map and longitudinal section showing approximate elevations of edge of glacial lacustrine beach ridge
(10 foot contour interval)

LEGEND

//// Main glacial lacustrine beach ridge

Contour control from:

- ● Seismic shothole
- X Bench mark
- o Highway ② profile

Existing 1:50,000 NTS map 84 C/4 with 50 foot contours

Tp. 82, R. 26, W. 5th Mer., 73 sets of bands (varves?) Plate IIIB) were counted in a 10-foot interval of sediment overlying till, which suggest a minimum life of 73 years for this lake. Some of the banding has probably been destroyed by soil formation.

The most prominent strand line to Lake Falher in the Grimshaw area, at approximately 2,000 feet elevation, may be traced almost without interruption for a distance of over 20 miles and continues out of the map-area to the northeast. Elevations of this strand line were not determined in the field. However, from plots of the strand line on a topographic map with 50-foot contour intervals, there appears to be a rise along it from southwest to northeast of approximately 25 feet within a distance of 16 miles. This is substantiated by the drawing of 10-foot contours using seismic shot-hole elevations in the vicinity of the strand line as points of control (Fig. 16). This is a tilt of about 1 1/2 feet per mile, the amount of uplift increasing in a northeasterly direction. Henderson (1959, p. 86) has obtained a tilt of 2 to 4 feet per mile in an easterly or northeasterly direction in the Sturgeon Lake map-area.

The amount of tilt, as shown on figure 16, merits some discussion. The main beach ridge was mapped from aerial photographs, and ground checks were made wherever a road crossed it (approximately every mile). The beach ridge was estimated to be as much as 6 feet high in some places and is almost non-existent in other places, although it shows up on aerial photographs as an almost continuous ridge. It is assumed that in places where the ridge is low or poorly defined, erosion has been responsible for destroying or lowering the ridge. Since the crest of the ridge was mapped and not the nick point, destruction of the ridge

locally results in a low elevation being obtained in places. This is the case over a distance of about four miles southwest from Grimshaw, where the beach is very poorly developed. Errors in positioning of shot-hole elevations or of the beach ridge on a map also provide room for error in estimating the amount of tilt of the strand line. Exact elevations on the top or base (nick point) of the main beach ridge would have to be determined to prove tilting conclusively.

The lacustrine deposits have a maximum thickness of 62 feet (see appendix of measured outcrop sections) and decrease in thickness to a feather edge along the shorelines described in preceding paragraphs. Near the edges of the lake the uppermost exposed sediment is a dark grey, poorly laminated, smooth clay or banded (varved?) clay and clayey silt. Farther from the lake edge, silt is the dominant sediment. The silt was probably deposited in a later, lower phase of the lake. *

Bands (varves?) of alternating dark grey clay and yellowish brown silt or clayey silt are present in most exposures of lacustrine sediment, but are usually very poorly preserved because of slumping and poor exposures. In one well exposed section of the upper 21 1/2 feet, 108 sets of bands or "varves" were counted (section at locality 65-125 in NE 1/4, Sec. 9, Tp. 82, R. 24, W. 5th Mer.). The thickest of these occur at the base of the section where a 6-foot unit of silt contains six 2-inch bands of clay. The thinnest varves are near the top of the section where 62 sets were counted over an interval of 18 inches.

On the assumption that the 108 sets or bands represent yearly deposits (i.e. that they actually are varves), it took 108 years to deposit 21 1/2 feet of material. Banding within the soil profile, if it was ever present, has not been

* Refer to fig. 40 and to Appendix III for results of grain size analyses of lacustrine materials.

preserved. Banding in the silt unit below the soil profile averages 3" per set of bands. Thus over the 2 feet of the soil profile, 8 sets may be assumed to have been present. As lacustrine sediments at this locality are approximately 50 to 55 feet thick (as indicated by nearby sections), then another 30 feet of material, mainly silt, should be present beneath the measured section. Deposition of this material, again assuming yearly deposition, was much more rapid than that of the upper clays and silts, as indicated by the increasing thickness of bands downsection. Assuming deposition of 2 feet per year (probably a conservative assumption since "varve" couplets in the lowest portion of the exposed section are only one-foot thick but thicker downwards), it took 15 years to deposit this portion. Thus the total life of the lake may have been in the order of 130 years. On the basis of varve counts, Henderson (1959, p. 77) concluded that Lake Falher III lasted at least 100 to 200 years in the Sturgeon Lake area.

The lacustrine deposits adjacent to Cardinal Lake and to Whitemud River have also been included by Taylor (1958, 1960) as being laid down in glacial "Lake Peace." The best developed beaches to glacial Cardinal Lake are at 2,145 to 2,151 feet elevation. Remnant beaches to as high as 2,200 feet are also found. As is the case with glacial Lake Falher, a shoreline strip characterized by discontinuous poorly developed strand lines, thin strips of sand and some gravel, and by patchy deposits of clay and silt over till, is found on the northwestern side of the glacial lake. The lake was probably shorter-lived than Lake Falher, as lacustrine deposits are thinner. However, exposures are rare and "varve" counts could not be made.

The lake at its maximum extent stretched out from its present position

in three arms, one to the south as far as highway 2, one to the west to connect with Last Lake, and one 6 miles to the northeast. Brownish clay and silty clay was deposited in the western arm and thin silt and clay in the northeastern arm. Banding (or varving) is poorly developed or not present.

The western arm of the lake had an inlet from the north and appears to have had an outlet for a short time to the west or southwest into the meltwater channel system near Leith (Little Burnt) River just west of the map-area. The spill point was at an elevation exceeding 2,150 feet just west or southwest of Last Lake.

The southern arm of the lake must have received very little deposition. Glacial till which shows well-developed glacial flutings in a general southwest-northeast direction is exposed at the surface. That this was indeed a former lake bottom is indicated by a broad level surface in a topographically depressed position, and by a well developed beach ridge at the south end. Lag gravels are locally present near the south end of this arm of the lake. The spill point connecting through a spillway system to the southwest lies at an elevation of approximately 2,140 feet (elevation obtained from highway profiles, Department of Highways, Province of Alberta).

The lake may have been drained eastwards for a short length of time through a rather poorly developed spillway off the present-day most easterly arm of the lake. The spill point was at an elevation of about 2,130 feet.

The northeastern arm of the glacial lake extended on either side of the present-day Cardinal Creek. The latest drainage of the glacial lake was in this direction. Cardinal Creek drains the present-day lake. The creek bottom elevation of Cardinal Creek at the point where it crosses highway 35, three miles northeast

of the north arm of the lake is slightly less than 2,100 feet. The stream is slow and sluggish and drainage is poor. Older deposits near the stream are masked by Recent floodplain deposition.

Lacustrine deposits adjacent to Whitemud River and along the north edge of the map-area are thin and only locally present. Brownish clays or varved clay and silt are the most common sediments. Beaches and other shoreline features were not formed or, at least, are apparently not preserved along the edge of the lake which lies within the map-area.

Postglacial Deposits and Features

Postglacial deposits and features fall into two broad groups, those associated with steep slopes, and those formed in low-lying areas. The first group includes eroded slopes, mud slides, slump and slide debris, scree and slope wash. The valley walls of the present-day Peace River valley have steep slopes formed by river downcutting. Where the valley walls have been cut in easily eroded glacial and buried channel materials, as is the case within the limits of the map-area, slumping and sliding has occurred and is still actively going on in some places. The second group includes Recent lake and alluvial deposits, river floodplain and terrace deposits and muskegs.

A rather unusual feature, which may reflect groundwater discharge at some time in the past, is a broad mound in Lsd. 12, Sec. 14, Tp. 82, R. 24, W. 5th Mer. (Plate VI). This mound is circular in plan view, rises approximately 6 feet above the surrounding plain, is approximately 160 feet across at the base, is flat-topped (about 60 feet across at the top) with a slight depression in the center which is reported to have been originally 8 feet deep by 20 feet across, but has since

been filled in. A well, also now filled in, is reported to have been dug within the depression and encountered potable water in good quantity at about 10 feet below the bottom of the depression. The mound is covered on the top and flanks by hard, dark-colored calcareous sinter, and the surrounding ground by thick white lime deposits up to two feet thick and containing abundant fossil snail shells. On air photographs, the mound resembles a dark-colored volcanic vent and the ground around it shows up as whitish in color for a radius of about 800 feet. The calcareous material is interpreted as representing calcareous shell material laid down in a pond existing after the draining of glacial Lake Falher.

It is suggested that the mound existed as an ice-cored "pingo" for some time in an arctic climate. Muller (1959) described pingos as hill-like formations which are found in the active state only in permafrost regions. They may rise 50 meters or more above the surrounding terrain. Their bases are generally circular or oval in shape and often measure several hundred meters in circumference. Their internal structure is characterized by the presence of a massive ice lens. They are a unique phenomenon of the periglacial region.

Leffingwell (1919) proposed that the origin of earth mounds (pingos) on the northern coastal plain of Alaska was due to hydraulic pressure. He stated (p. 154): "At the beginning of the Arctic climate ... the ground became frozen progressively downward... As soon as the downward freezing interfered with the flow of the groundwater, hydraulic pressure was set up. This pressure may have acted so slowly as to bulge up and fracture the frozen crust locally without any great outflow of water..."

Porsild (1938) accepted Leffingwell's view for the origin of pingos on

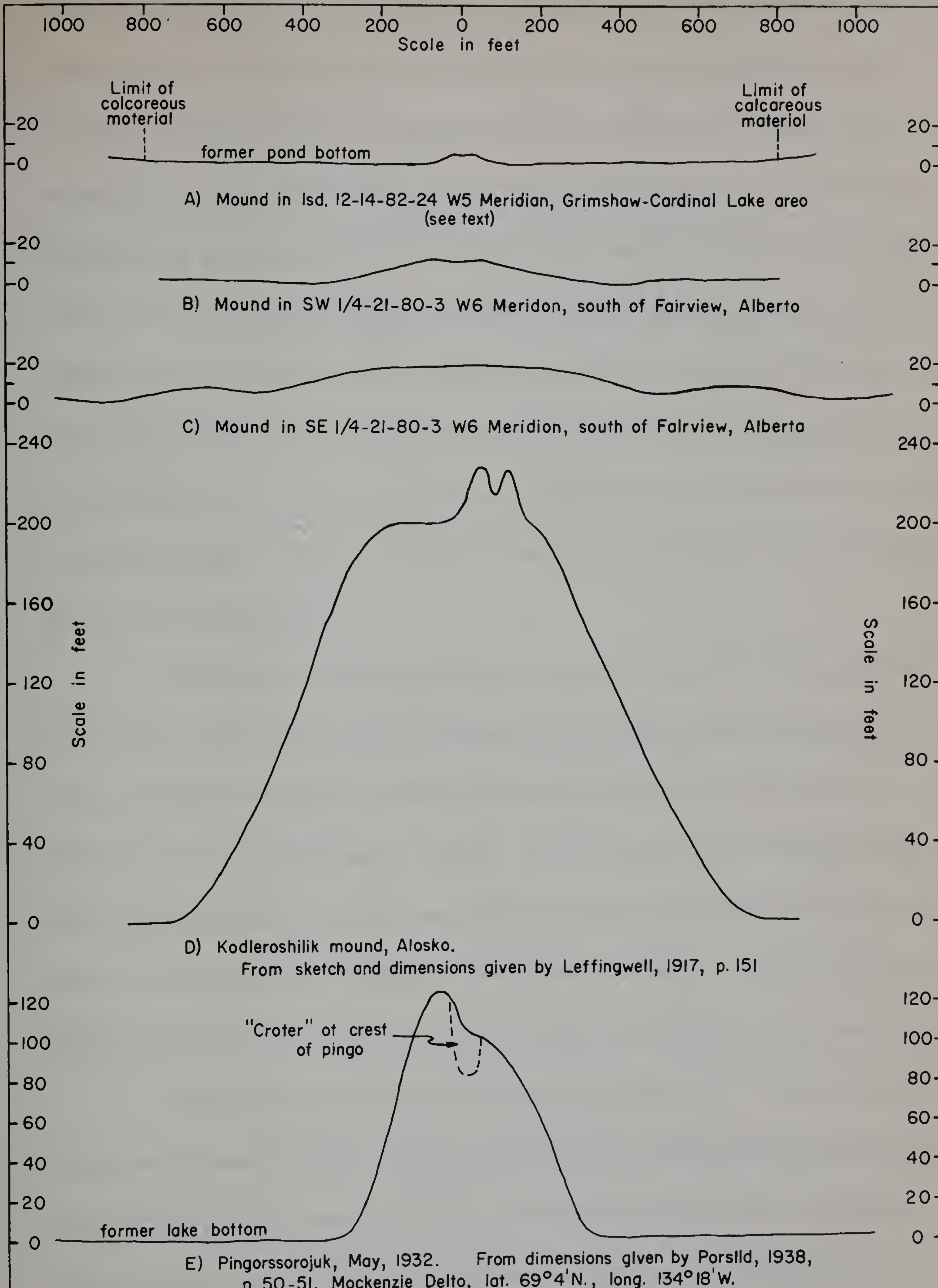


Figure 17
Cross-sections through mounds of Peace River district (A, B & C), and through large pingos of arctic North America (D & E)
Vertical exaggeration: 5 times

sloping ground where hydraulic pressure could be expected to be quite great. He stated, however, that for pingos located on flat ground removed from slopes, hydraulic pressure would not be expected to be great enough to cause such an upheaval. He proposed (p. 55) a formation "by local upheaval due to expansion following the progressive downward freezing of a body or lens of water or semi-fluid mud or silt enclosed between bedrock and the frozen surface soil. Muller (1959) supported and expanded on Porsild's hypothesis. MacKay (1962) provided further refinements to the Porsild method of pingo formation. Bostrom (1967) attributed pingo formation in the Mackenzie delta area to artesian head provided by water expulsion brought about by compaction of sediments in an area affected by tectonic subsidence.

Recent work (MacKay, 1962, and others) has shown that permafrost in present-day arctic regions can be fissured, thin or absent beneath bodies of surface water. Such places provide points of weakness where upheaval might occur (MacKay, 1962, p. 53; Bostrom, 1967). In the case of the mound in the Grimshaw area, previously described, the availability of groundwater for its formation is shown by the presence of a shallow flowing well across the road from it and a strong spring less than half a mile to the east (also reported by Rutherford, 1930, p. 45).

Larger features similar to the mound described, but also showing some important differences (Figs. 17B,C; Plate VII), have been observed by the author south of Fairview and near Spirit River in the Peace River district of Alberta. They can be as large as half a mile or more in diameter and up to 20 feet high. All are isolated features or occur in small groups with each mound in a group being separated from the others by a considerable amount of level ground. Two

low, rather poorly developed mounds of the type near Fairview and Spirit River are located in the Grimshaw-Cardinal Lake area in Sec. 3, Tp. 83, R. 23, W. 5th Mer. A small spring at the head of a gully is located near one of these mounds. Some of the mounds have gullying associated with them which usually starts from near the periphery of the mound. These mounds, although much larger and somewhat different than the small mound described above, may owe their origins to a process of formation similar to that described by Porsild. The small mound and the larger mounds show a greater similarity when viewed from the ground than when viewed on aerial photographs (compare Fig. 17A to 17B & C, and Plate VI to Plate VII).

The internal composition of the mounds of the Peace River district could in no instance be examined by the author, but those in the Grimshaw area occur in areas of thick lacustrine materials. The surficial materials in the Spirit River and Fairview districts have not been mapped but appear to be lacustrine in the vicinity of the mounds. A section measured in a gully-cut at the periphery of one of the mounds in the Grimshaw area (locality 65-99) was composed of 35 feet of lacustrine material, mainly laminated silt in the lower 20 feet and poorly exposed clay in the upper 15 feet.

The large mounds of the Peace River district present a ring-like appearance on aerial photographs caused by vegetation and moisture differences in depressional and high areas. There is usually a depressional area around the base of the mound, while the mound itself may or may not have a central depression. In some cases (Fig. 17C) there is an outer depression, a circular ridge, an inner depression, and a central mound. Most of the mounds examined on aerial photographs are

composed of more than two "rings". Porsild (1938, p. 56) presents an aerial view of a pingo in advanced state of decomposition which is quite similar to the features observed in the Peace River district. Water-filled crescentic moat-like ribbons of water surrounding the pingo shown in Porsild's photograph accentuate the ring-like effect. These are possibly responsible in part for the ring-like appearance observed in the mounds of the Peace River district.

Pingo breakdown by melting of the ice core results, in some cases, in a geomorphic feature characterized by an outer rim or ridge and a large central depression (Muller, 1959, Plate III). Well preserved fossil features of this type have been reported in Wales and Belgium (Pissart, 1963). The features in the Peace River district differ from these in that they are actually low, broad mounds in which the central depression is subdued or absent. Of the few present-day pingos for which subsurface information is available, most are found in regions underlain by sands, predominantly in the fine- to medium-grained size range (MacKay, 1962, p. 29). The fossil forms in Wales are partly underlain by gravels (Pissart, 1963). It is here postulated that the difference in external shape of the fossil forms of Wales, as well as of the present-day collapsed pingos, and those of the Peace River district, is due in part to the nature of the underlying materials. In the Grimshaw area, exposed sections near the mounds indicate that silt and very fine sand forms the main water-bearing zone and is overlain by lacustrine clay and laminated clay and silt. Intrusion of water to form a pingo ice core must have carried considerable silt along with it. The silt thus intruded upwards could be replaced by silt and sand drawn in laterally, provided that a sufficiently large section of unfrozen material was available in a lateral direction. In the case in

which a central mound is ringed by an outer ridge, later reactivation of pingo activity may be represented. This is not an uncommon situation in present-day pingos (Muller, 1959, Plate IV).

Mounds in the Peace River district have been reported previously (Henderson, 1959; Mathews, 1963). Mound swarms in the Sturgeon Lake area (Henderson, 1959, p. 48-56) consist of closely spaced doughnut-shaped mounds, mostly averaging 250 to 570 feet in diameter, 5 to 10 feet high and with a central depression 2 to 3 feet deep. They are composed mainly of till, although some are overlain by a few feet of clay or silt. Some mounds are formed of silt. Where mounds are especially closely spaced, the inter-mound trenches commonly show remnants of a polygonal outline.

Henderson (p. 54) considers the mounds to have formed as the result of bulging of till material under pressure generated by the growth of large ice wedges formed in polygonal-fractured or patterned ground of greater than usual dimensions. He attributes the mantle of clay and silt that occurs on the top of many of the mounds to have been deposited in a lake formed during an ice re-advance. The silt mounds are considered to be younger in age, formed after drainage of the lake in which silt deposition occurred.

Mounds similar to those of the Sturgeon Lake area have been described from the Fort St. John area of British Columbia (Mathews, 1963, p. 12, 16-18). These mounds are commonly 100 to 300 feet in diameter at their bases, and from 5 to 20 feet high. Some exceptional ones are as much as 1,500 feet in diameter and 40 feet high. They may be closely clustered, as in the Sturgeon Lake area, or widely separated. Although the internal composition, other than for the top

foot or two, could not be determined, all the mounds occur where late glacial lacustrine sediments form a continuous mantle in excess of 10 feet thick, and locally more than 100 feet thick. Several mounds are capped by fossiliferous calcareous silt which pinches out toward the base of the mounds. A few of the mounds consist of well-bedded sand.

Mathews (p. 17) notes the resemblance of these mounds to the "prairie mounds" of south-central Alberta (Gravenor, 1955) which are described as local accumulations of detritus from a wasting ice sheet. He states that the position of the mounds in areas of thick lacustrine sediment precludes the ablation hypothesis of Gravenor. The present author concurs in this opinion. Mathews (p. 17) also states that the wide spacing of some of the mounds rules out Henderson's ice-wedge hypothesis, at least for the widely spaced mounds. He feels that the mounds formed long after the ice had withdrawn and after the accumulation of many feet of lacustrine sediments. He mentions that the close association of local pond silts with some of the mounds suggests a link with pingos, but does not consider that the mound shape would persist upon melting of the clear ice core of the pingo. He suggests, however (p. 18), that "displacement of water-saturated soil, rather than water alone, during development of permafrost" could account for the formation of the mounds and for the preservation of positive relief after melting of the core.

The mounds discussed in the present report differ from those of the Sturgeon Lake area in the following respects:

1) They are isolated features and do not occur in swarms;

2) They are (except for the mound in Lsd. 12, Sec. 14, Tp. 82, R. 24, W. 5th Mer.) usually much larger than mounds of the Sturgeon Lake area, although the height ; basal diameter ratio is

usually less;

3) They present a ring-like appearance on aerial photographs, usually with more than 2 rings being present, while those of the Sturgeon Lake area are doughnut shaped;

4) They occur in areas of thick lacustrine sediment, while most of those in the Sturgeon Lake area are composed of till;

5) They vary greatly in diameter, while those of the Sturgeon Lake area are much more uniform in size.

It is considered that the mounds in the Sturgeon Lake area owe their origin to processes different than were operative in the case of the mounds in the Grimshaw, Fairview, and Spirit River areas.

The author has not examined the mounds of the Fort St. John area either from aerial photographs or on the ground and Mathews has not provided detailed enough descriptions or illustrations to enable any closer comparison to be made between these mounds and the mounds of the other areas.

HYDROLOGY

Introduction

The work of Rutherford (1930) and Jones (1966) has indicated a high groundwater potential for the Grimshaw area. The present work attempts to evaluate this potential more fully. Groundwater aspects investigated included:

1) A survey of water wells within the map-area which included, where possible, measurement of depth of well and depth to water and the collecting of a water sample for chemical analysis.

2) Examination of water-well drillers' logs and other data on file at the Research Council of Alberta.

3) Examination of field phenomena related to groundwater discharge or recharge, including examination of spring discharges.

4) Drilling of test holes to determine depth and lithology of water-bearing materials, ranges of water chemistry from one aquifer to another, vertical and lateral ranges of water chemistry within aquifers, and changes in head with drilling depth.

5) Bail and pump testing to determine aquifer characteristics and to predict rates of production.

6) Chemical analysis of groundwater samples.

7) Installation of water-level recorders to determine long-term water-level fluctuations in response to climatic and other effects.

Groundwater Occurrence

Basic Principles

Meinzer (1923, pp.21-24) divides water beneath the surface of the ground into two major zones, that in the zone of aeration (vadose or suspended water) and that in the zone of saturation (ground or phreatic water). The zone of saturation is defined as "the zone in which the functional permeable rocks are saturated with water under hydrostatic pressure. " The water table is " the upper surface of a zone of saturation except where that surface is formed by an impermeable body."

Water occurs within the ground in interstices or void spaces within a rock or soil. The porosity of the material is an expression of the percentage of void space to the total volume of the mass (earth material plus void space). Porosity can range from nearly zero to over 50%. Within the zone of saturation the void spaces are entirely filled with water. However, due to molecular and surface tension forces, not all of this water can be removed. These forces are strongest in fine grained (clayey) materials, which although they may have high porosity will yield very little water to a well. The specific yield or effective porosity is an expression of the amount of water which can be drained and will be some fraction of the total porosity of the material. Permeability is a measure of the rate at which a fluid will move through a material. The effective porosity and permeability are highest in materials in which the adhesive forces are low as in coarse grained materials such as sand and gravel. These materials, therefore, form the major aquifers or groundwater reservoirs in any area.

Wells

Enclosure 6 shows the wells within the map-area together with well depth and depth to water. The probable formation or unit in which the well is completed is also shown. There is some uncertainty in some cases as to which formation or unit forms the aquifer, but an interpretation was made to fit the geology as indicated by geological and surficial geology maps and a map of thickness of surficial deposits.

Formations which have been used for supplies of potable water include the following:

Dunvegan Formation . Soft, poorly consolidated sandstones of this formation yield generally hard water, high in iron and sulphate, in approximately the southeastern one-third of the area. Water lower in total solids and generally of much better quality is obtained in the eastern portions of the north half of the area (p. 69). Sustained yields of up to 40 imperial gallons per minute (igpm) can probably be obtained from this formation (p. 86).

Grimshaw gravels. Water obtained from these gravels is almost always of potable quality, medium hard, and low in iron and total solids. The extent of these deposits is outlined on enclosure 2. The gravels are not usually full saturated. Most wells which tap this supply have only a few feet of water due to partial penetration but drawdowns are small, even under sustained pumping at high rates. With sufficient penetration of the saturated section and proper well completion, yields of over 100 igpm should be obtainable in most places (p. 85).

Intermediate level sands and gravels. A number of wells have been completed in these younger, more deeply buried deposits. The sands and gravels are much thinner than the Grimshaw gravels, and are under confined conditions.

Water quality is fair to poor, as iron, sulphates, and total solids may exceed the recommended limits for potable water (Table 3, p. 67). Sustained yields of up to 5 igpm are indicated by preliminary testing (p. 86) but higher yields are likely to be obtained in places where the deposits are thicker. A few wells on the northwest side of Cardinal Lake have been completed into these deposits. Other wells are located in a belt running from north of Grimshaw, southwest through Berwyn, to south of Brownvale.

Glacial till. A few low-yield wells have been completed in sandy or gravelly phases of glacial till. Water quality is usually poor, being high in hardness, iron, sulphate, and total solids.

Glacio-lacustrine deposits. Small amounts of generally poor quality water can be obtained in places from fine lacustrine sand. One well is known that was completed in the sand and gravel of a glacial lake beach, although these deposits generally lie well above the zone of saturation and are not of sufficient extent to hold enough perched groundwater to supply a well.

Glaciofluvial deposits. A dug well, south of Berwyn, completed in kame sand yielded a small supply of water high in iron. Glaciofluvial materials may yield small amounts of water elsewhere in the map-area, but are not generally utilized.

Recent alluvial gravels and sands. These are utilized chiefly on the terraces adjacent to the Peace River. The chief detriment to quality is high values of iron and hardness. Large amounts of water are obtainable from these materials in the vicinity of the Peace River.

Other possible aquifers. Other possible aquifers which have not, so far as known, been utilized or tested within the limits of the map-area include the sands and gravels of the deeply buried Shaftesbury Channel and the sandstones of the Peace River Formation. The former deposits can be as much as 800 feet below ground level, they may be partially drained, and the water quality could be poor as recharging groundwaters have to pass through great thicknesses of poorly permeable fine-grained materials. Water quality in the Peace River sandstones could be poor for the same reason. In addition to this, both of these deposits are located near or at the end of major groundwater flow systems, and highly mineralized waters may be expected.

Springs and Seepages.

A spring is defined as a place where water issues from the ground, rock, or soil in a discernible flow. It is to be distinguished from a seepage, in which flow is not discernible. The following discussion applies to seepages as well as to springs. Spring locations are shown in figure 21 and on enclosure 6.

Four types of springs have been recognized. These are grouped according to the classification of Bryan (1919) as -

1) Contact springs

2) Border springs

3) Valley springs

The latter two types are varieties of depression springs as classified by Bryan. A fourth type of spring not included in Bryan's classification is recognized. These are termed "valley bottom springs."

Contact springs. Bryan (1919) states that "where porous rock overlies impervious material the water that accumulates in the porous rock is forced to the surface at the contact." In the present paper a contact spring is defined as a spring that emerges from permeable material at or near the contact with underlying less permeable or relatively impermeable material. This type of spring can occur well up on hill and valley slopes. Only one spring has been assigned to this type. This is a spring which occurs approximately half-way down the side of a steep gully approximately 120 feet deep. Section 65-139 is exposed on the opposite bank of the gully (Plate VIIIA). The probable contact between the till and overlying lacustrine silt (and fine sand?) is marked by a prominent shoulder in the measured section which is accentuated by heavier growth of vegetation than on the slopes above and below it. The spring occurs at the same approximate elevation as the till-silt contact and although the gully side here is heavily wooded and no exposures are present it is interpreted as being a contact spring. The spring flow has been tapped by a wooden trough stuck into the gully side many years ago. Flow from the trough was timed at nearly 2 igpm. In addition to the spring, seepages must occur along the contact, as a lush growth of mosses, Equisetum and small willow extend horizontally along the gully side for approximately 300 feet. Low soft spots occur here and there over this interval. The spring site itself is marked by an even heavier growth of Equisetum, mosses, and large willow. These plant types extend down, less prolifically, from the spring site to the bottom of the gully, being concentrated near the line of flow of discharging spring water. A few small tamarack were also noticed, while on the fringes, birch and spruce intermixed with poplar are dominant. The normal growth along the wooded side of the gully is mainly poplar and some spruce.

At the site of the discharge, a fan of fine sand and silt has been deposited, and iron precipitate is conspicuous indicating that the emerging water carries fine particles in suspension and iron in solution. Plate VIIIB illustrates contact seepages at another locality.

Border springs. Bryan (1919) has defined border springs to illustrate a specific example of spring discharge in desert areas. He states, "Border springs are due to the change in gradient at the line between the alluvial slopes and central flat of a desert basin....... Groundwater is brought to the surface primarily by the change in slope, but the dense silts and clays of the center of the basin tend to act as a dam to prevent further movement down the slope." It is here considered that this term may be applied to other regions as well as to desert areas. Numerous springs and seepages which emerge from the southeasterly (downslope) edge of the Grimshaw gravels are considered to be of this type. The change in gradient occurs where the relatively steep southeasterly edge of the gravels is abutted and overlapped by till and/or glacio-lacustrine clays. This also results in the damming effect necessary to cause the groundwater to move out of the more permeable material as springs and seepages. A line of springs trending northeast-southwest across the south half of the map-area is thus formed.

The rate of flow was measured with a triangular-notched weir at two different springs. The measurements were made at the end of September, 1965. Seasonal fluctuations in rate of flow have not been determined, although all the springs discussed below flow all year around. The Whitelaw spring in Lsd. 11, Sec. 35, Tp. 81, R. 1, W.6th Mer. is located just outside of the map-area. A flow of 135 igpm was measured. The combined flow from a number of small springs which occur in Lsd.9, Sec. 28, Tp.83, R.23, W.5th Mer. was measured at

between 45 and 50 igpm. At two localities where the flow rate could not be measured accurately because of low boggy channel conditions, the rate was estimated by visual comparison with the two springs for which the rate was determined. Both are large springs and both are of the same order of magnitude as the Whitelaw spring if not slightly larger. The flow for each is estimated at 135 igpm. The springs are (1) a spring in Lsd. 5, Sec. 7, Tp. 85, R. 21, W. 5th Mer., approximately 7 miles east of the map-area and 8 miles due north of the bridge across the peace River at Peace River town, and (2) a spring located on the Peace River Crossing Indian Reserve, approximately in Sec. 9, Tp. 82, R. 25, W. 5th Mer. With respect to the classification of springs by rate of discharge (Meinzer, 1923, p. 53), the three large springs are fourth order springs (100 U.S. gpm to 1 second-foot of discharge) and the smaller discharge represents a fifth order spring (10 to 100 U.S. gpm).

The three large springs form the source supply of perennial streams (i.e. perennial if winter freezing is not considered), while the smaller spring flows into an area of low boggy ground (muskeg) out of which drainage is intermittent. Similar areas of low boggy ground elsewhere off the southeastern edge of the Grimshaw gravels indicate spring and seepage conditions and are usually drained by intermittent streams. Many of the southeasterly flowing tributary streams to the Peace River thus owe their origin to spring or seepage flow out of the Grimshaw gravels.

<u>Valley springs</u>. "Valley springs are due to the abrupt change in slope at the line between the bounding valley walls and the edge of a flood plain," (Bryan, 1919). Although no such springs have been mapped within the limits of the map-area, they are common along the Peace River valley elsewhere. Three such springs have been examined outside of the area, one two miles to the east and two near Peace River town 8 miles east of the area.

The lack of such springs within the limits of the map-area is probably a reflection of the geology. Valley sides show much slumping of mainly clayey, relatively impermeable materials. Although seepages may occur, it would be difficult for any major springs to form under these conditions. The two springs near Peace River town are both located near outcrops of Peace River sandstone. The springs have probably developed in places where the sandstone is slightly more permeable, possibly because of fracture permeability, and flow has been localized. Both springs have flow rates of less than 1 igpm. The third spring is located in river lot #22 of the Shaftesbury Settlement. The valley slopes at this locality are slumped and overgrown and no exposures could be obtained. Consequently, the source materials could not be determined. Flow rates appear to be low, however, and mainly in the nature of numerous small seepages. All three of the springs have built fan-shaped deposits of fine-grained material which are marked by phreatophytic vegetation.

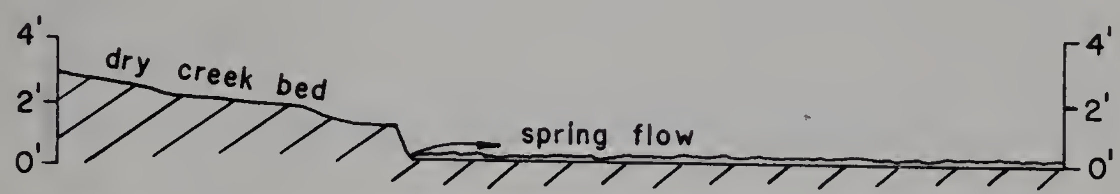
Valley bottom springs. A valley bottom spring is here defined as any spring which is located at or very near the bottom of a valley which is usually but not necessarily occupied by a stream or river. Three sub-types are recognized: a) Stream-bank springs; springs that occur on stream banks under effluent stream conditions and which may or may not derive their flow from bank storage; b) Stream head springs; springs that form the headwaters of a valley stream and are mainly responsible for the formation of the stream and its valley. Most of the springs discussed under the category of border springs are of stream head type but have been classified differently because of the obvious nature of the geologic control in their formation; c) Re-emergence springs; springs that occur in the bottom of creek beds and whose flow is dueto re-emergence of water derived from further upstream which flows over clayey or silty materials but through coarse gravelly materials of the stream bed. Re-emergence springs are not considered to be important for the purposes of this discussion. Their locations are not shown in figure 21 or on enclosure 6.

Valley bottom springs are numerous and are mainly responsible for maintaining streamflow during low flow periods. Streams which increase in rate of flow downstream must receive groundwater additions along their course. Streams which maintain the same rate of flow (under equal channel conditions) downstream or in which the rate of flow decreases are considered to receive little or no additions of groundwater along their course. Streams of dominantly one type or the other occur within the map-area, and of course, any one stream may change from one condition to the other along different stretches of its course.

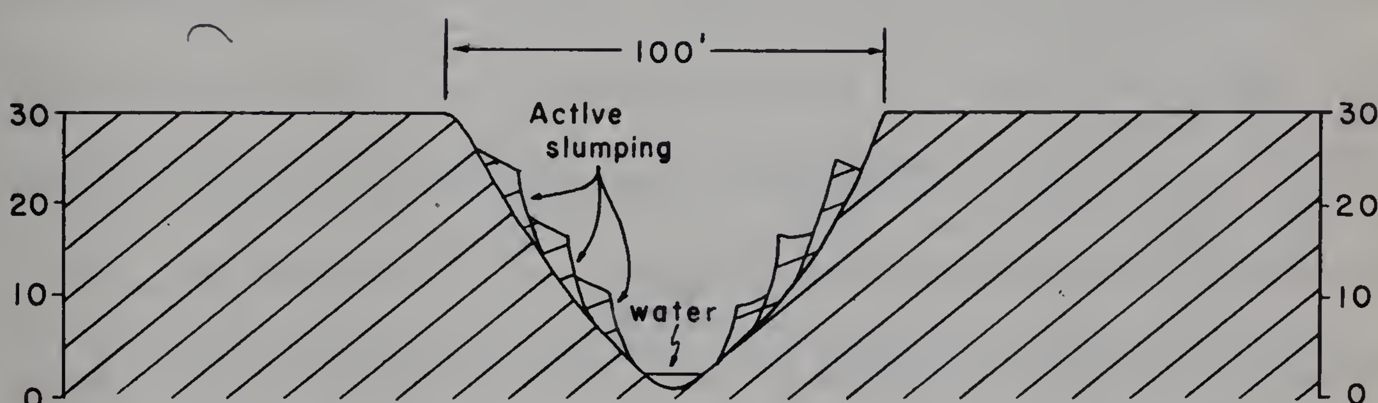
Of the five valley bottom springs examined within the area two are of the stream-bank sub-type and three of the stream head sub-type. All the springs were examined in September of 1966 when low flow conditions existed. Many of the stream beds examined were dry or had only very slight flow or standing pools of water, probably fed by diffuse seepage through poorly permeable materials. This is the case in areas of great till thickness within the buried Shaftesbury Channel (i.e. in the extreme southwestern corner and in the most southerly portion of the map-area). In addition, in these areas the lacustrine material which overlies the till is thin and mainly clayey. By comparison, in the southeastern portion of the area, where all the observed valley bottom springs are located, glacio-lacustrine material overlying till is thick and is predominantly silt to very fine sand in the lower portions. It is from these silts and sands that most of the spring flow is derived.

A spring of the stream-bank sub-type is shown in plate VIIB. The picture shows the typical dirt fan built out from these springs and the associated phreatophytic vegetation. Small rivulets of water flow across the fan. The largest of these flowed at approximately 1 igpm. Total discharge from the spring area may have been in the order of 3 igpm. Orangey-red slime due to iron bacteria is also associated with the discharge. Iron bacteria slimes have been found to occur at most of the spring localities of the valley bottom type which were examined, and its presence in stream water or on stream banks can be used as a guide to locating springs and seepages. This has been reported previously from other areas in Alberta (Le Breton, 1966).

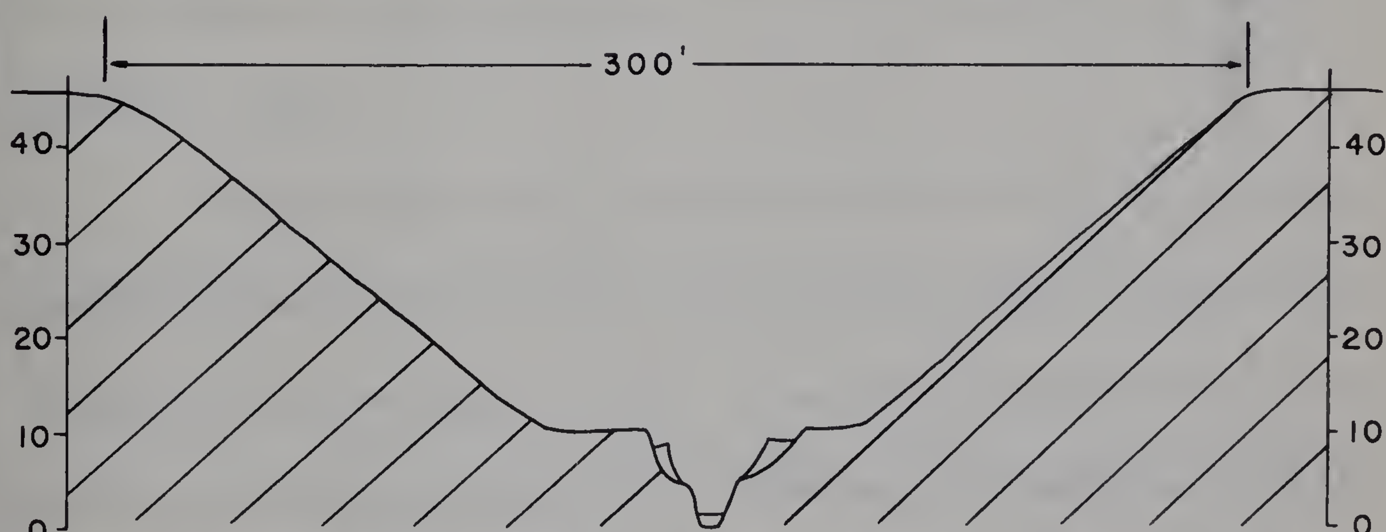
The three stream head spring sites all exhibit active downcutting and extensive slumping of the valley sides. In all cases, the stream valley (dry) extends upstream from the spring source, but the spring location is marked by a



Long profile along stream bottom through spring site



Section across stream valley 200 feet downstream from spring



Section across stream valley $\frac{1}{4}$ mile downstream from spring

Figure 18 - Profile of stream bed and sections across stream valley associated with spring in SW $\frac{1}{4}$ -32-82-22 W5th Meridian.

prominent step in the stream bed above the point of discharge and a high gradient above the step. The dry stream bed above the step has been channeled by runoff waters in easily eroded glacio-lacustrine clay and silt. Figure 18 is a sketch of the stream-bed profile and two cross sections across the valley of one of these streams.

Natural Movement of Groundwater

Introduction

Groundwater within the zone of saturation is not static, but moves according to hydraulic principles. Mathematical models to describe the nature of groundwater motion in two dimensions within a homogeneous isotropic and porous medium have been derived by Hubbert (1940) and Toth (1962, 1963). Toth (1962) has demonstrated that groundwater flow patterns can be greatly altered by the introduction of a highly permeable lens into an otherwise homogeneous medium. Freeze (1966) and Freeze and Witherspoon (1966), using the work of Toth as a basis, applied the mathematical model to three dimensional, nonhomogeneous, anisotropic cases.

All the above models are based on the fact that a force potential, called the fluid potential, exists within any body of groundwater. This potential is not everywhere the same within the body. Lines of equal potential may be drawn which are termed equipotential lines. Movement of groundwater occurs from areas of high potential to areas of low potential, and lines drawn orthogonally* to the equipotential lines represent directions of groundwater flow.

Toth (1963) has demonstrated that lines of flow may be grouped into flow

*in sections with unexaggerated vertical or horizontal scale

systems. He defines a flow system (p. 4806) as "a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region; they can be intersected anywhere by an uninterrupted surface across which flow takes place in one direction only." Since Toth's model assumes a homogeneous, isotropic medium, topographic surface expression provides the main controls on water-table levels, and consequently on groundwater movement.

Toth (1963, p. 4806) defines three different types of flow systems (Fig. 19). A local flow system "has its recharge area at a topographic high and its discharge area at a topographic low that are located adjacent to each other." An intermediate flow system is one where "although its recharge and discharge areas do not occupy the highest and lowest elevated places, respectively, in the basin, one or more topographic highs and lows may be located between them." A regional flow system is one in which the "recharge area occupies the water divide and its discharge area lies at the bottom of the basin." A recharge area (Toth, 1966a, p. 30-31) is defined as "an area where water is absorbed which eventually reaches a part of the aquifer that is in the zone of saturation." A discharge area is "an area where water is removed from the zone of saturation." The fluid potential, if measured in a vertical well, decreases with depth in recharge areas, and in discharge areas will either increase, decrease or remain unchanged. Thus, flowing wells may be expected to occur in discharge areas. Anomalously high or low potentials are due to permeability changes within the materials penetrated.

Freeze (1966) has demonstrated that in interlayered materials of contrasting permeabilities flow will be mainly in a vertical direction within the low

permeability materials and mainly in a horizontal direction within the high permeability materials (Fig. 20). This has also been demonstrated with the use of piezometer nests in groundwater discharge areas (Meyboom, et al, 1966; see especially Fig. 20).

Groundwater Movement Within the Area of Study

The general aspects of groundwater movement within the map-area are discussed here. Groundwater movement within the Grimshaw gravels is considered in the following section. As shown by Freeze (1966), movement in the till and in other low permeability materials overlying the gravels will be essentially downwards and will provide recharge to the gravels. Areas of downslope pinch-out of the gravels and sands against poorly permeable materials are the discharge areas. These are marked by springs and seepages.

The same type of pattern is to be expected within the intermediate level gravels and sands and within the Dunvegan Formation. The buried Shaftesbury Channel is largely filled with relatively low permeability materials in its upper few hundred feet. Sands of the Dunvegan Formation and of the intermediate level deposits truncate downslope against the fill material and groundwater will move upwards from this point. Consequently, flowing wells are common in the area adjacent to the buried valley. The pattern of groundwater movement is probably similar to that shown in Fig. 20C. Flowing wells do not occur across the stretch where the Berwyn Channel enters the Shaftesbury Channel, probably because of a hydraulic connection between the intermediate level sands and gravels and the deeper lying permeable materials in the lower parts of the Shaftesbury Channel. Thus, flow will not be diverted upwards but will continue downwards into the

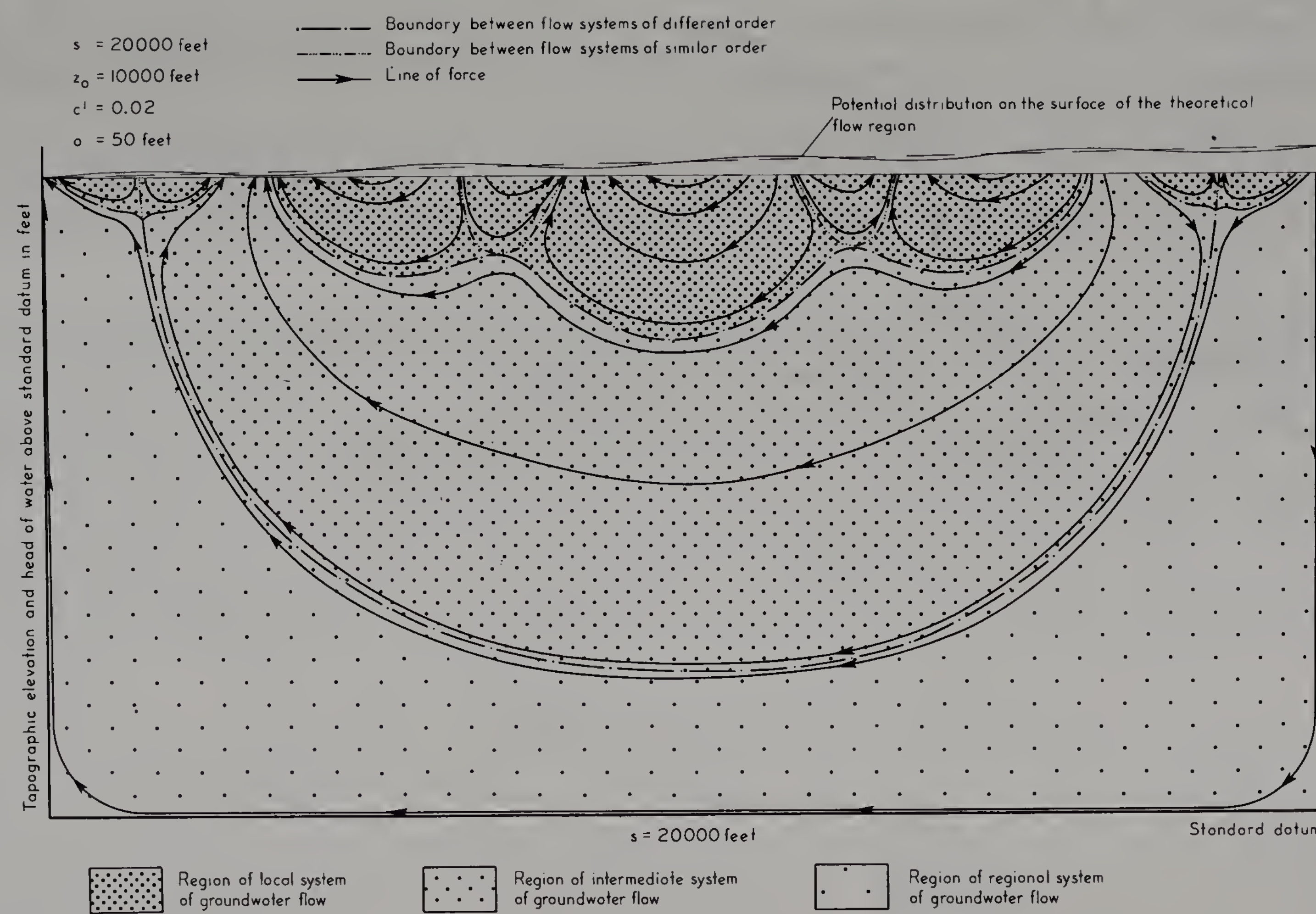
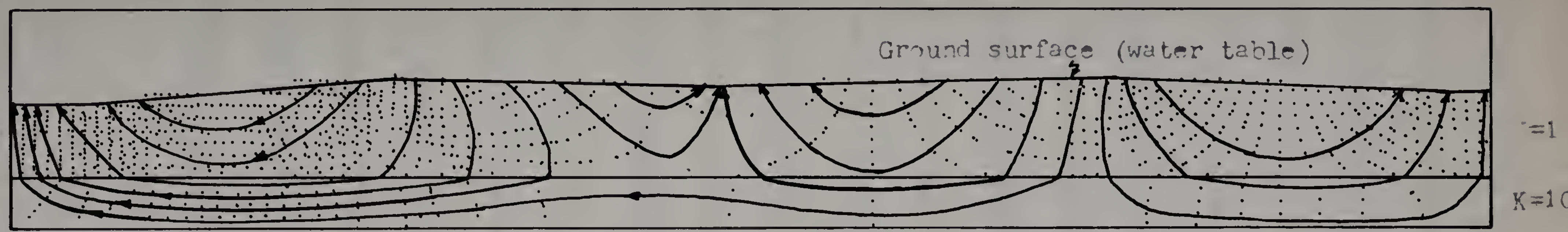
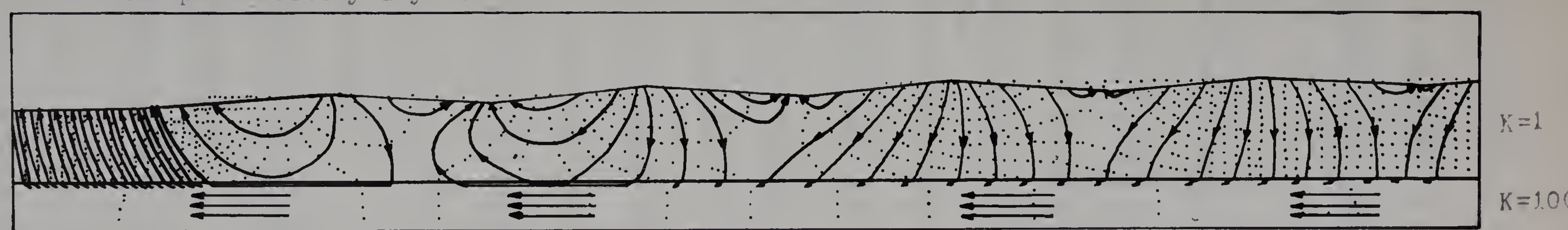


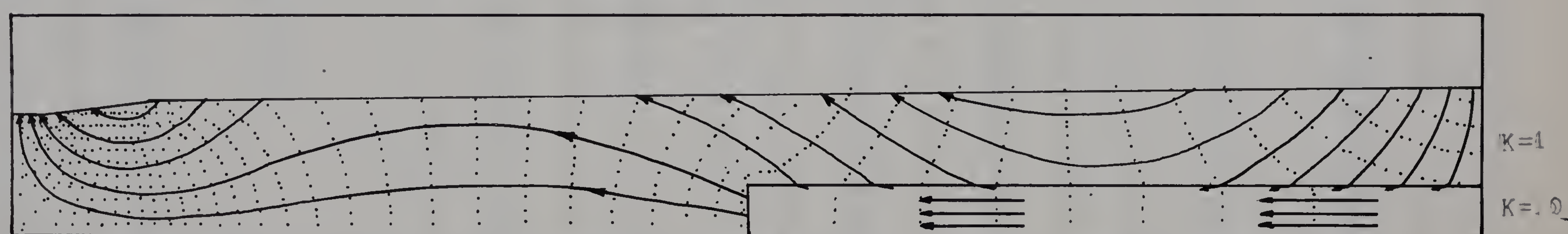
Figure 19 - Theoretical flow patterns and boundaries between different flow systems (after Toth, 1963)



20A. Flow system in area of rolling topography, in which a high permeability layer underlies a low permeability layer.



20B. Flow system in area of hummocky topography, but with a regional slope, in which a layer of very high permeability underlies a low permeability layer.



20C. Effect of a lens of high permeability material on the flow system, in area of flat regional slope.

Figure 20 - Theoretical flow patterns in different geologic and topographic settings, as solved by computer analysis. (after Freeze, 1966, figs. 21d, 20t & 20l.)

Legend - K= average permeability
. Computer-plotted point of hydraulic potential
Flow line

deeper sands and gravels. Since no wells are known to tap the deeply buried deposits of the Shaftesbury Channel, water levels within them have not been obtained. However, it is likely that if the materials are thick and highly permeable, they will be partly drained through spring and seepage flow from the walls of the Peace River valley.

In the northern part of the map-area, permeability pinchouts do not appear to be important and a deeply incised river valley is not present. Water supplies are obtained from surficial sands and from Dunvegan sandstones. It is probable that these are both of about the same permeability and may be considered to form one hydrologic unit. The Whitemud Hills form the recharge area. All wells are located in topographically low areas not far from Whitemud River and Cardinal Creek. Nearly all are shallow and have high water levels. Two of the deeper wells flow. It is probable that all are located within a discharge area. This is also borne out by the presence of salt precipitates on the ground surface in many places (Fig. 21). These precipitates are the residue left behind from the evaporation of water. High concentrations of salts indicate constant availability of water for evaporation which can only occur in areas of high water level under groundwater discharge conditions.

Water Levels and Groundwater Movement in Grimshaw Gravels and Adjacent Formations

Contours of water levels in the Grimshaw gravels are shown on enclosure 7. As the Grimshaw gravels are only partially saturated, the water is considered to be under water-table conditions. The depth to water ranges from zero to over 80 feet (Encl. 6). The depth to water was measured during the course of

the well survey and the elevation of the well in relation to the road allowance was estimated. The well elevation was later estimated by means of a 10-foot contour interval map constructed from seismic shot-hole elevations and the existing 50-foot contour interval map (p. 11). Elevations of test holes were determined by means of a surveying altimeter and some of these were later checked by levelling. Elevations of some wells southwest and southeast of Cardinal Lake were determined by levelling. These provided a check on the altimeter and estimation methods. The results obtained by all methods are considered to be sufficiently reliable for the purpose desired. Because of the generally level topography over large areas, only small errors are introduced by estimating elevations.

Some of the features shown on the map of water levels are discussed in the following paragraphs. The general gradient of the water table is quite gentle, less than two feet per mile in some places. Steeper gradients are obtained toward the pinchout edges of the Grimshaw gravels and can be as high as 70 feet per mile above areas of spring discharge, although slopes of this magnitude are maintained only for short distances above the spring sites. It is a general rule that water levels are higher in elevation under topographically high areas than under topographic lows. This is generally true for the Grimshaw area, although a few anomalies exist.

A linear groundwater high (or groundwater "mound") is present north and northwest of Brownvale. This is believed to exist because of the presence of glaciofluvial sand and silt overlying the Grimshaw gravels in this locality. Intervening till is thin and possibly absent in places. The glaciofluvial materials form a natural catchment and a relatively high proportion of rainfall will infiltrate into

the ground. If only a thin clay or till barrier exists between the glaciofluvial sands and the underlying gravels downward movement of groundwater through this barrier would be relatively more rapid than through laterally contiguous thicker till deposits. The result is a groundwater mound in the gravels beneath the glaciofluvial materials.

A pronounced low in the water table is present west and northwest of Berwyn. A possible explanation for this low may lie in the presence to the south of the low of the intermediate level gravels and quicksands to depths of up to 180 feet below ground level. A hydrologic connection between these lower sands and gravels and the higher level Grimshaw gravels could result in the draining of water out of the Grimshaw gravels into the lower deposits.

Two similar lows exist off the northeast arm of Cardinal Lake, where springflow and seepage out of the gravels are probably responsible for keeping the water levels down. Water usage by the town of Grimshaw is likely a contributing factor in the case of the more southerly of these lows.

The water levels within the Grimshaw gravels show a definite relationship to the level of Cardinal Lake. Cardinal Lake lies in a depression, within which, in large part, the Grimshaw gravels are not present. However, these gravels do adjoin the lake in places on the northeastern and eastern sides at lake level (Encl. 2). Thus a direct hydrologic connection between the lake and the gravels exists. The Grimshaw gravels on the western and southwestern sides of the lake appear to be separated from the lake by intervening till and clay.

Since groundwater driven by the force of gravity will flow from areas of high water level to areas of low water level, it is possible to determine approxi-

mate flow directions from the map. It is apparent that most of the flow from the gravels is southeasterly to the areas where the water discharges as springs and seepages. There is also some apparent flow in the direction of Cardinal Lake, mainly from the north and west, and some from the south. Seepages have been reported along the north shore of the lake.

Flow from the lake into the Grimshaw gravels appears to exist at the northeastern end of the lake. Flow from the southern end may also occur but, in this case, there is a comparatively thick clay and till barrier through which the lake water must percolate before the gravel beds are reached. Consequently, flow in this direction can be considered to be almost negligible. A hydraulic gradient away from the lake also appears to exist at the northwestern end of the lake. This is considered to be a "false" gradient existing only because of the practically impermeable nature of the earth materials at this location. This view is supported by the existence of groundwater discharge features at the surface at this locality (Fig. 21). Thus, the main outflow from the lake in the form of groundwater is from the northeastern arm of the lake to the southeast. The surface drainage is through the sluggish meandering Cardinal Creek which drains the lake to the northeast into Whitemud River.

Water Levels and Groundwater Movement Outside the Area of Grimshaw Gravels

Water levels in shallow wells less than 50 feet deep are shown on enclosure 7. These levels will generally approximate the water table. Water levels in deeper wells have not been contoured but will generally conform to the

rules, as discussed in the previous sections, that in groundwater "discharge" areas levels will rise, drop, or remain unchanged with increasing well depth and in "recharge" areas will drop with increasing well depth (p. 57).

Field Phenomena Relating to Groundwater Movement

It has been pointed out by several authors, notably Toth (1966b), that certain surface features are related to groundwater. The majority of these are located in discharge areas and include springs, seepages, salt precipitates, flowing wells, and highly mineralized surface waters. Recharge areas are characterized by a lack of these features, and surface waters are not highly mineralized. Groundwater levels and chemical quality of groundwater are influenced by the type of groundwater movement. Differences in vegetation patterns may also reflect differences in groundwater conditions. The relationship of the groundwater chemistry to groundwater movement is discussed in the next section (p. 65).

It was not the purpose of this study to map field phenomena in detail. However, some observations were made (Fig. 21). In general, the Whitemud Hills and the areas underlain by the Grimshaw gravels are areas of recharge. These features are topographically high. Almost all other areas are areas of discharge, including practically the entire regional slope extending from the area of the Grimshaw gravels down to the Peace River. This is borne out by the presence of abundant salt precipitates, flowing wells, springs, and highly mineralized surface waters. It should be pointed out that groundwaters discharging out of the Grimshaw gravels are not highly mineralized and thus constitute an apparent anomaly to the classification here presented. These waters do show, however, the great influence that differences in earth materials exert on groundwater chemistry and that caution

must be used in distinguishing between recharge and discharge areas on the basis of water chemistry alone.

The obvious influence of local geology on the observed field features is shown by springs out of the Grimshaw gravels, by contact springs, and by the presence of flowing wells in the area of truncation of the Dunvegan Formation by the Shaftesbury Channel. However, even if the geology were not known in detail, inferences as to its nature could be made from the observed field phenomena.

A mound which resembles a collapsed pingo (p.37 , Fig. 18, Plate VI) located in Lsd. 12, Sec. 14, Tp. 82, R. 24, W. 5th Mer., may be indicative of the presence of an aquifer at shallow depths within a discharge area. The association of a strong spring and a shallow flowing well near the mound (p. 39) suggests such a relationship. If so, similar mounds within the Peace River district may be clues as to the presence of shallow aquifers. Somewhat similar mounds of larger size exist in the Peace River district but their relationship, if any, to groundwater is not clear. It is here assumed, however, that they are discharge area phenomena, inactive at the present time.

The map of field phenomena relating to groundwater movement (Fig. 21) shows mainly discharge area features. Diagnostic recharge area features, at best, are difficult to determine. In the map presented (Fig. 21) no attempt has been made to separate discharge and recharge areas, due mainly to scarcity of definite control within recharge areas.

Groundwater Chemistry

Introduction

Water samples were collected from more than 300 wells within the map-area. Chemical analyses of the water were carried out by the Provincial Analysists, the late Mr. C.E. Noble and Mrs. Kathleen Strausz. In addition, some surface and spring waters were collected and analyzed. Cations determined were Ca^{++}, and Mg^{++}, while Na^{+} and K^{+} were calculated. Anions determined were HCO_3^{-}, CO_3^{--}, Cl^{-}, and NO_3^{-}, while SO_4^{--} was calculated. Total solids, ignition loss, hardness, alkalinity, pH and iron were also determined.

The purpose of the analyses was:

1) To separate areas of waters suitable for human consumption from areas of unsuitable waters;

2) To relate groundwater chemistry to local geology and groundwater movement.

The results of analyses are here presented in a series of maps showing contours of equal concentration of the particular constituent shown. Each map is discussed separately.

It should be noted that these analyses are for waters from aquifers generally suitable for rural use, for consumption by either humans or livestock. As such, they generally represent the best shallow groundwaters available in any particular area, both in terms of quality and quantity. In places, anomalous values of various chemical constituents are obtained. These can be due to one of several factors. Some of these are: 1) contamination of the supply; 2) shallow or deep well completed in a formation not normally used for water supply, either because of its

inferior characteristics or because of excessive drilling depth; 3) presence of a local aquifer; 4) absence of a suitable aquifer, resulting in use of poor quality water; 5) completion within a flow system different than that tapped by other wells.

The composition, areal extent, and depth of burial of the water-bearing formation, and its position within the groundwater flow systems has a very great influence on the type of water that will be obtained, the best quality waters being from fairly extensive, shallowly buried gravels and coarse clean sands located in topographically high areas. Water obtained from clay, till, shale, silt or local more permeable lenses within these materials tends to be of poorer quality due to the length of time the water must spend within these materials from the time it enters the ground to the time it reaches the well. This is largely determined by the position of the well and the aquifer material within the groundwater flow system as, for example, a shallow well dug into near-surface silt on a topographic high is likely to obtain good quality water, while a similar well dug into similar material within a topographic low at the base of a long regional slope of mainly clay or till would most likely obtain water of inferior quality.

The geological cross sections (Encl. 4; Fig. 14) show the locations of water wells along the line of section and the chemical composition of the water from these wells. These sections illustrate the striking difference in quality of water from the Grimshaw gravels as compared with water from adjacent materials.

Recommended limits of chemical constituents in drinking water are shown in table 3. The recommended limits for most livestock are higher.

The sources of the various chemical constituents in groundwater have been discussed by several authors, notably Hem (1959). As detailed petrographic

Table 3

Recommended Limits of Chemical Constituents in Drinking Water

Constituent	Recommended limit (ppm) (U.S. Public Health Service)	Recommended or "practical" limit (ppm) (in general use in Alberta)
Total solids	500	1600 to 2000
Sulphate	250 (as SO_4)	500 (as SO_3) for municipal supply 800 for private supply
Chloride	250	500
Iron	0.3 (Fe + Mn)	0.3
Nitrate	45 (as NO_3)	10 (as N)
Magnesium	125	125
Fluorine	1.5	1.5
Soda (Na_2CO_3)	not stated	675

work and chemical analysis of earth materials has not been carried out in the map-area it is difficult to assign definite source materials in the Grimshaw-Cardinal Lake area. A few general comments, however, may be made.

The anions present in the groundwaters of the map-area are, in order of abundance, sulphate, bicarbonate, carbonate, chloride, and nitrate. The cations are: calcium, magnesium, sodium, and potassium. Hem (1959, p. 100) states that sulfate can accumulate in water to a rather high concentration because the cations taken into solution from rocks generally do not form insoluble compounds with sulfate. High concentrations of sulphate are common within the map-area, and contribute largely to the high total solids content in many wells. The major source of bicarbonate, carbonate, and magnesium may be calcium and magnesium carbonates within the soil profile. Nitrates are likely derived from the decomposition of organic materials. High concentrations of nitrates are most likely due to contamination by barnyard seepage or manure and may be accompanied by high concentrations of chloride. Other sources for these and the other chemical constituents are present, but cannot be summarized here because of lack of detailed work in this field. The processes of solution, precipitation, oxidation, reduction and ion-exchange are operative in bringing about changes in the chemistry of groundwater as it moves through the ground.

Total solids

The concentration of total solids, in parts per million, in well waters is shown in figure 22.

The general pattern shown by the contours on this map is essentially the same as that shown on the following maps (Figs. 23 to 29) and illustrates the strong influence of length of flow path, together with the nature of earth materials on the chemistry of groundwaters.

The best quality waters, in terms of total solids, are in areas underlain by Grimshaw gravels, where concentrations of under 500 parts per million are generally obtained. Low values are also obtained at the eastern end of the Whitemud Hills from wells completed in sandstones of the Dunvegan Formation or in surficial sands. No wells have been drilled in the Whitemud Hills, but wells off the northern and southern flanks obtain total solids concentrations of less than 1,000 parts per million. These wells appear to be completed in surficial materials. Nearby deeper wells that are slightly higher in total solids are probably completed in sandstones of the Dunvegan Formation.

Total solids concentrations increase rapidly in downslope directions away from the Grimshaw gravels and away from the Whitemud Hills. Concentrations of over 3,000 parts per million are obtained in wells in the regionally low areas adjacent to the Peace River, Whitemud River, and Leith (Little Burnt) River. These are the major drainageways within and near the map-area. These low areas represent the areas of upward-moving, relatively highly mineralized groundwaters of regional flow systems. Other topographically low areas show similar, though lesser, high total solids concentrations.

Local geology can modify the general pattern just discussed. Near Cardinal Lake, for example, relatively high total solids concentrations are found, except in the northeastern portion where the Grimshaw gravels are present at or near lake level. Even within the area of Grimshaw gravels an increase in total solids in a downflow direction is apparent as, for example, on the southwestern side of Cardinal Lake. This may be due also, in part, to a greater thickness of till and clay overlying the gravels in this vicinity. As the gravels are not usually saturated, there may be a significant contribution of mineralized waters from the till and clay in this area. If the gravels were saturated, and under sufficient pressure, water should move upward from the gravels into the overlying till and clay.

An area of relatively low concentrations of total solids (less than 1,000 ppm) is found in Tp. 82, R. 24, W. 5th Mer. in waters of comparatively deep wells mostly completed in intermediate level gravel and sand or in sandstone of the Dunvegan Formation. From the position of these wells on the regional slope, and considering the depth of burial of the aquifer materials, higher concentrations of total solids might be expected. The relatively low concentrations may be due to a direct hydraulic connection between these aquifer materials and the Grimshaw gravels, with additions from overlying materials being comparatively small. Movement through fine-grained materials would thus be held to a minimum.

Anions

Relative percentages in equivalents per million of bicarbonate, together with carbonate ions of the total anions, are shown on figure 23. Bicarbonate is by far predominant. The same general pattern is shown as was presented on the map of total solids; the highest bicarbonate-carbonate percentages occurring in

areas underlain by Grimshaw gravels and adjacent to the Whitemud Hills.

The other anions which were determined (sulphates, chlorides, and nitrates) make up the difference between the values presented and 100 per cent. Of these, sulphate is dominant, nitrates in high concentrations are found only in contaminated waters, and chlorides are present in minor amounts. Figure 24 shows the areal distribution of chloride ions in percentage of total anions.

The amount of nitrate in parts per million is shown in figure 25. In low concentrations, up to about 5 parts per million, the pattern presented is similar to that of the previous maps. Higher concentrations are likely indicative of contamination of the well supply.

Cations

Relative percentages in equivalents per million of calcium and magnesium ions of the total cations are shown on figure 26. The pattern is again similar to that shown on the previous maps; the highest calcium-magnesium values are obtained in areas underlain by the Grimshaw gravels and adjacent to the Whitemud Hills. Of the other cations determined, sodium is present in large amounts locally; potassium in small, almost negligible amounts. Thus, the difference between the contour values shown onfigure 26 and 100% represents essentially the percentage of sodium in equivalents per million of the total cations.

Calcium-magnesium ratio

Contours of the calcium-magnesium ratio (Fig. 27) show the same general pattern of the previous maps; generally, high values of calcium to magnesium are obtained over the area of the Grimshaw gravels and near the Whitemud Hills and decrease toward discharge areas. However, some important reversals

of this pattern occur, both in the area of the Grimshaw gravels, and in downslope directions from it. The reasons for these reversals are not known. They occur in the southeastern portion of the map-area where the calcium-magnesium ratio increases in a downslope direction, and just out of the map-area to the northeast where magnesium predominates over calcium in waters from the Grimshaw gravels.

Iron

The amount of iron present in well waters in parts per million, is shown on figure 28. Again, the pattern is similar to that shown on the previous maps, although not as well developed, probably because of the extremely small amounts which are being dealt with. The lowest values are obtained in waters from the Grimshaw gravels and in wells near the Whitemud Hills.

pH

Values of pH are shown on figure 29. The pH ranges from 6.85 to 8.8. In general, pH values appear to decrease with distance away from areas underlain by Grimshaw gravels, but this is not true everywhere. North of the Whitemud Hills the pH increases in a downslope direction. The highest pH values within the map-area are attained in this general area. Seaber (1965), in delineating chemical changes laterally and with depth within a single formation in New Jersey, noted (p. B23) that changes in pH parallel changes in bicarbonate and carbonate content and are related to iron content. In the southern part of the Grimshaw-Cardinal Lake area this appears to be generally true, higher pH occurring in areas of higher bicarbonate-carbonate content and of lower iron content. The area north of the Whitemud Hills, however, demonstrates a reversal of this pattern. The reasons for this are not known.

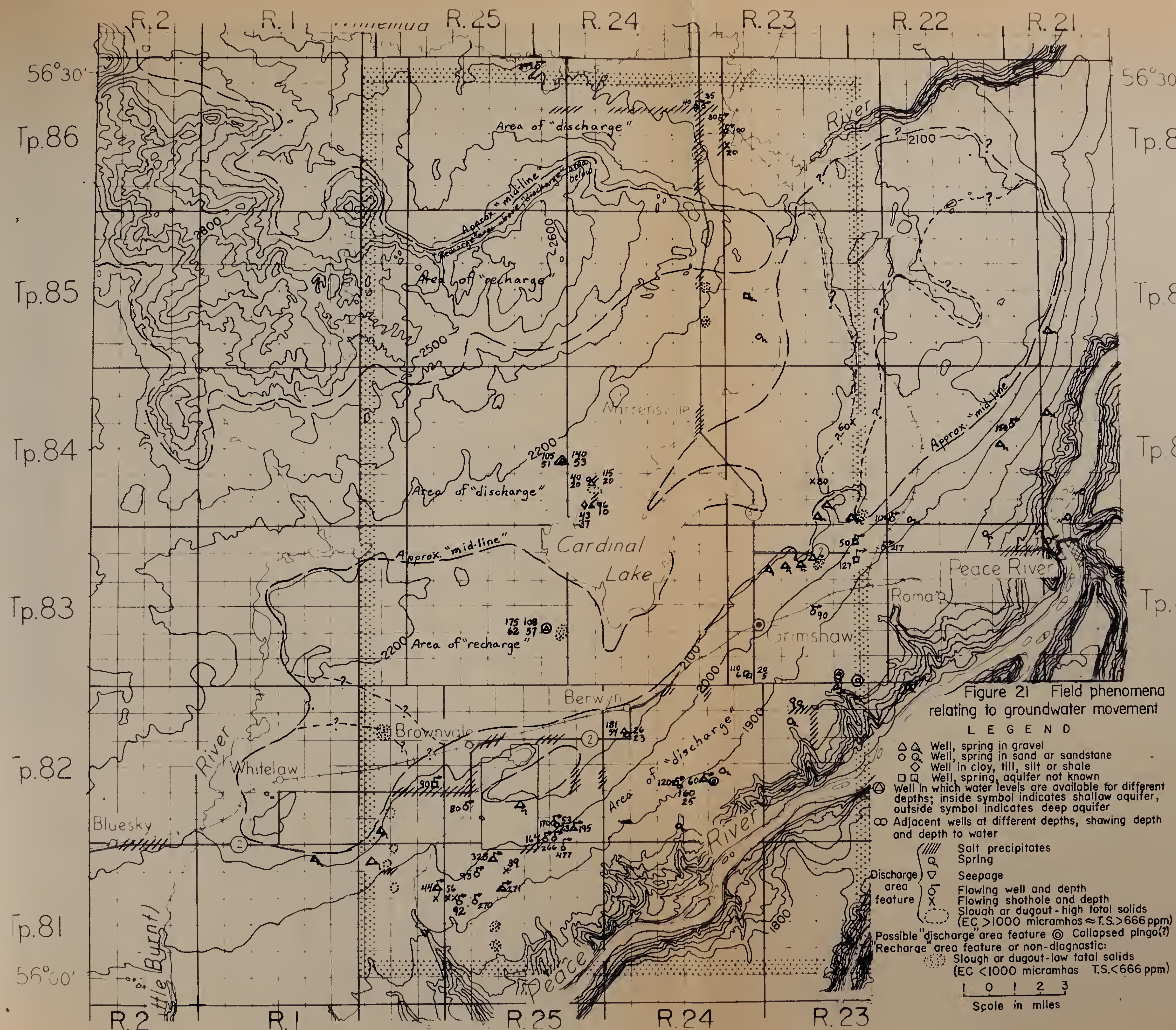


Figure 21 Field phenomena relating to groundwater movement

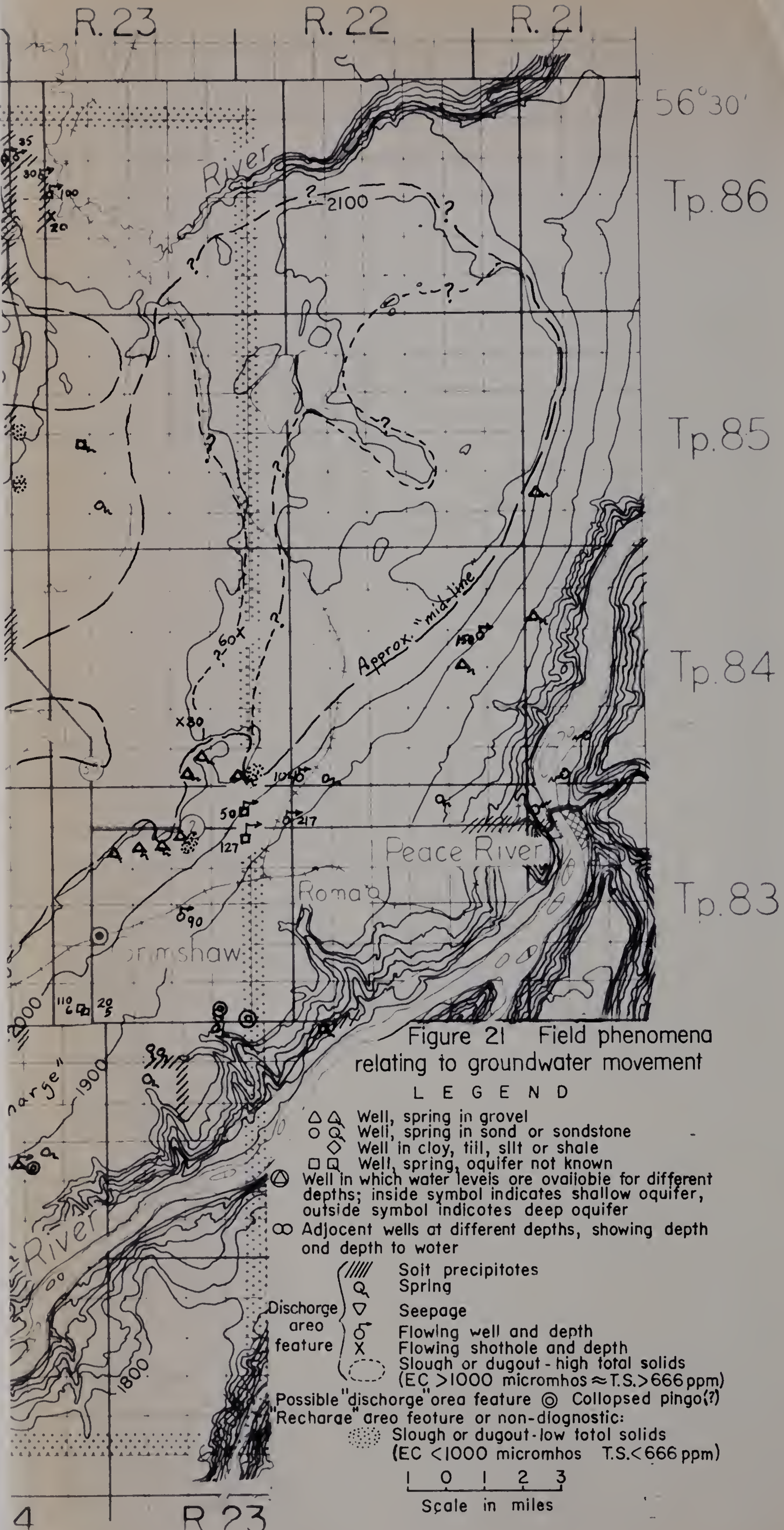


Figure 21 Field phenomena relating to groundwater movement

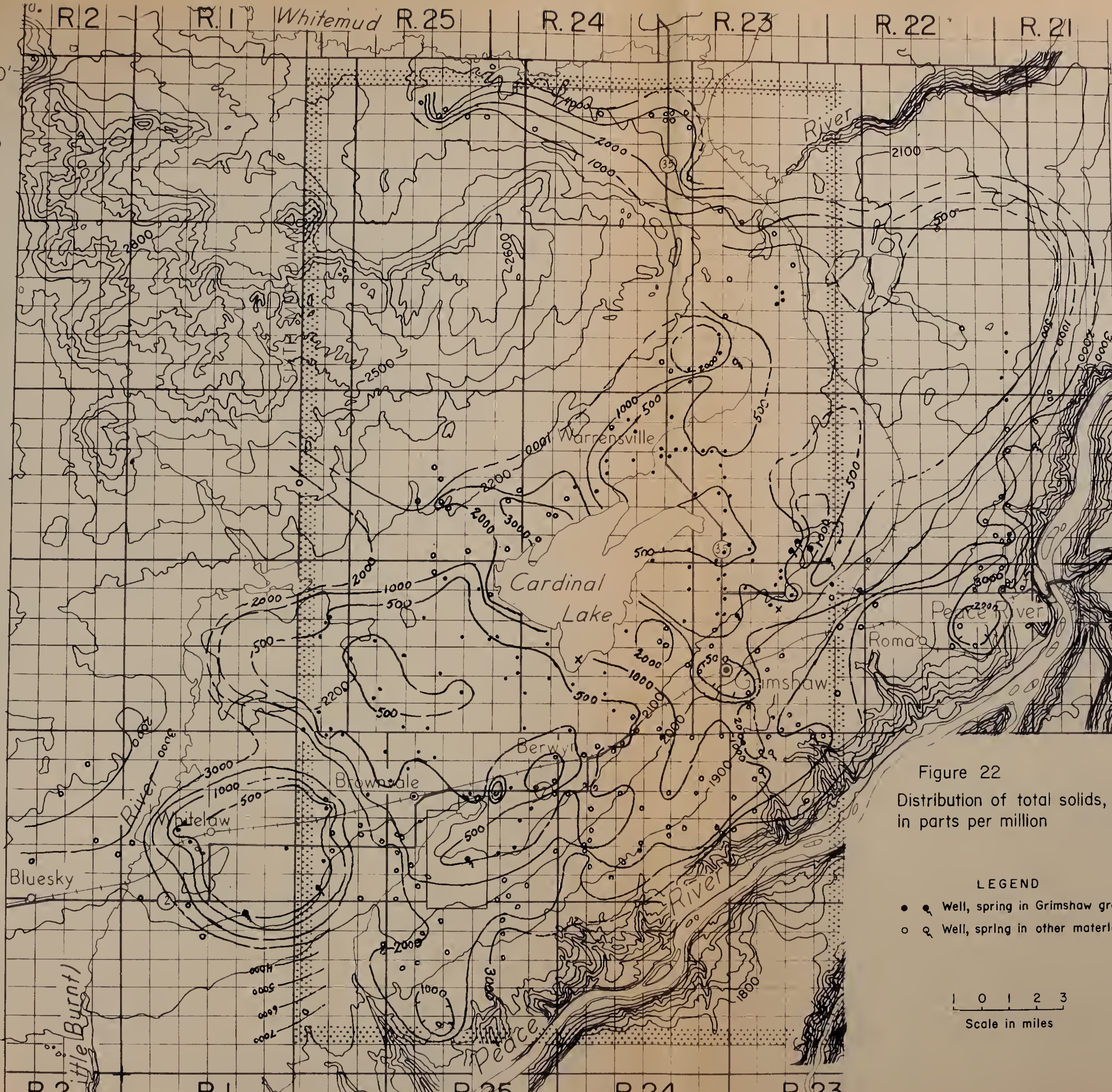


Figure 22
Distribution of total solids,
in parts per million

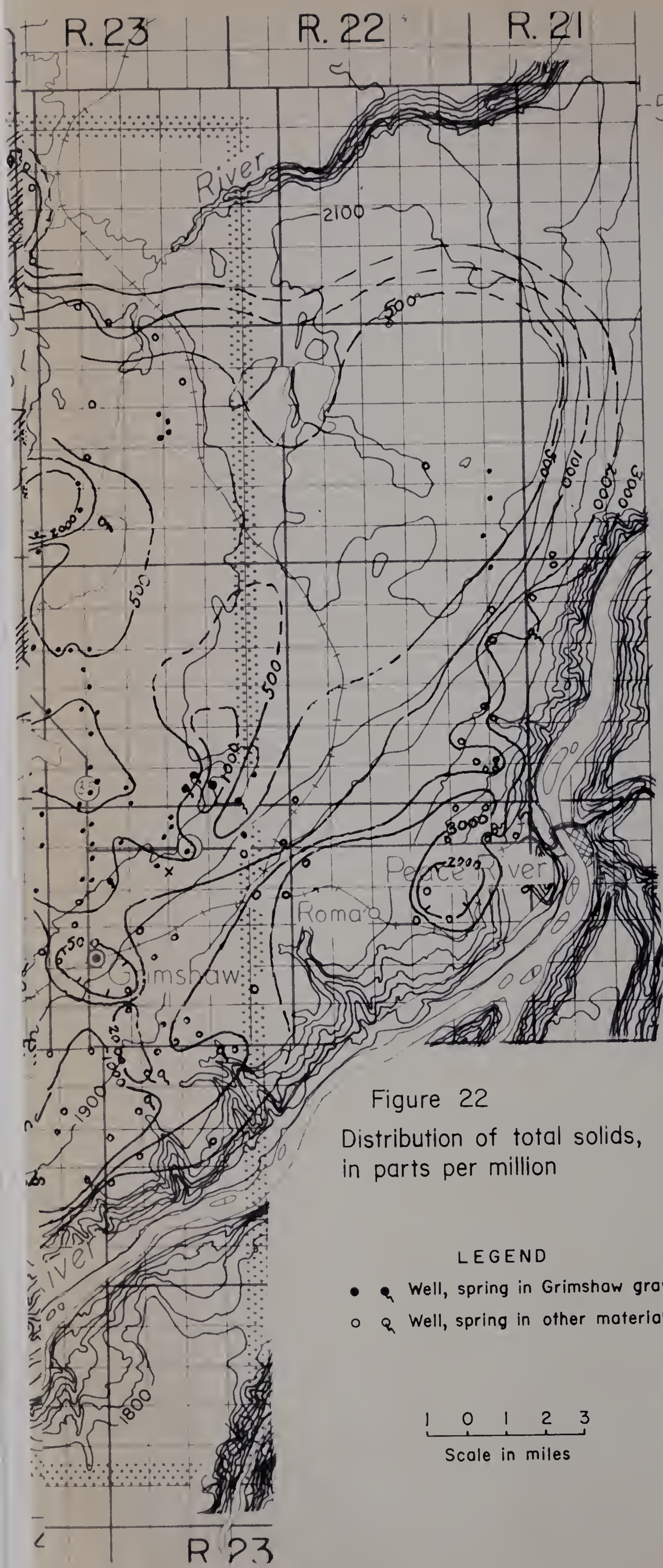


Figure 22
Distribution of total solids, in parts per million

LEGEND
Well, spring in Grimshaw gravels
Well, spring in other material

Scale in miles

Figure 23

Distribution of bicarbonate and carbonate ions as percentage of total anions

LEGEND

● Well, spring in Grimshaw gravels

○ Well, spring in other material

0 1 2 3

Scale in miles

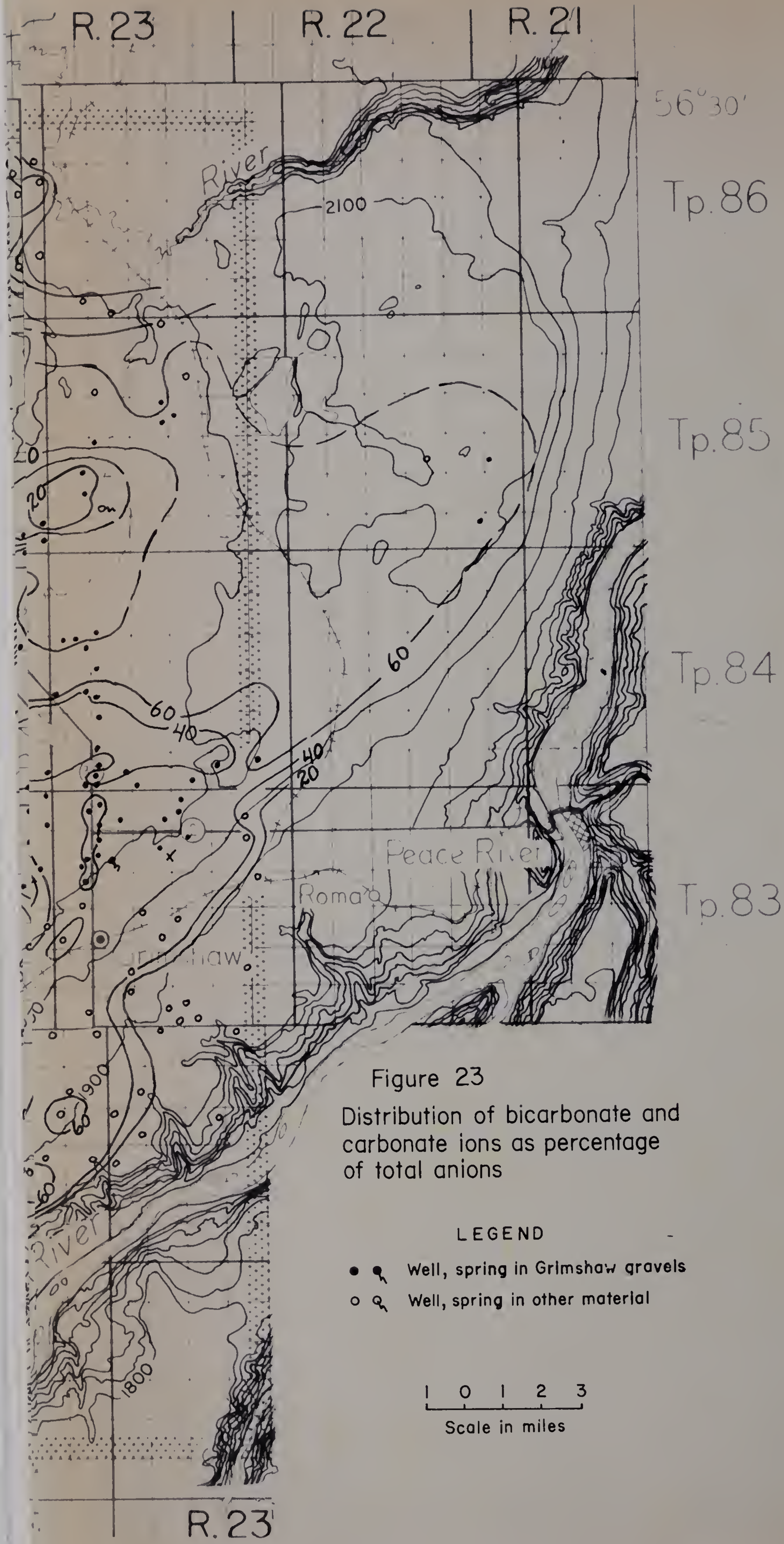


Figure 23

Distribution of bicarbonate and carbonate ions as percentage of total anions

LEGEND

● ⚲ Well, spring in Grimshaw gravels

○ ⚲ Well, spring in other material

1 0 1 2 3

Scale in miles

Figure 24
Distribution of chloride ions as percentage of total anions

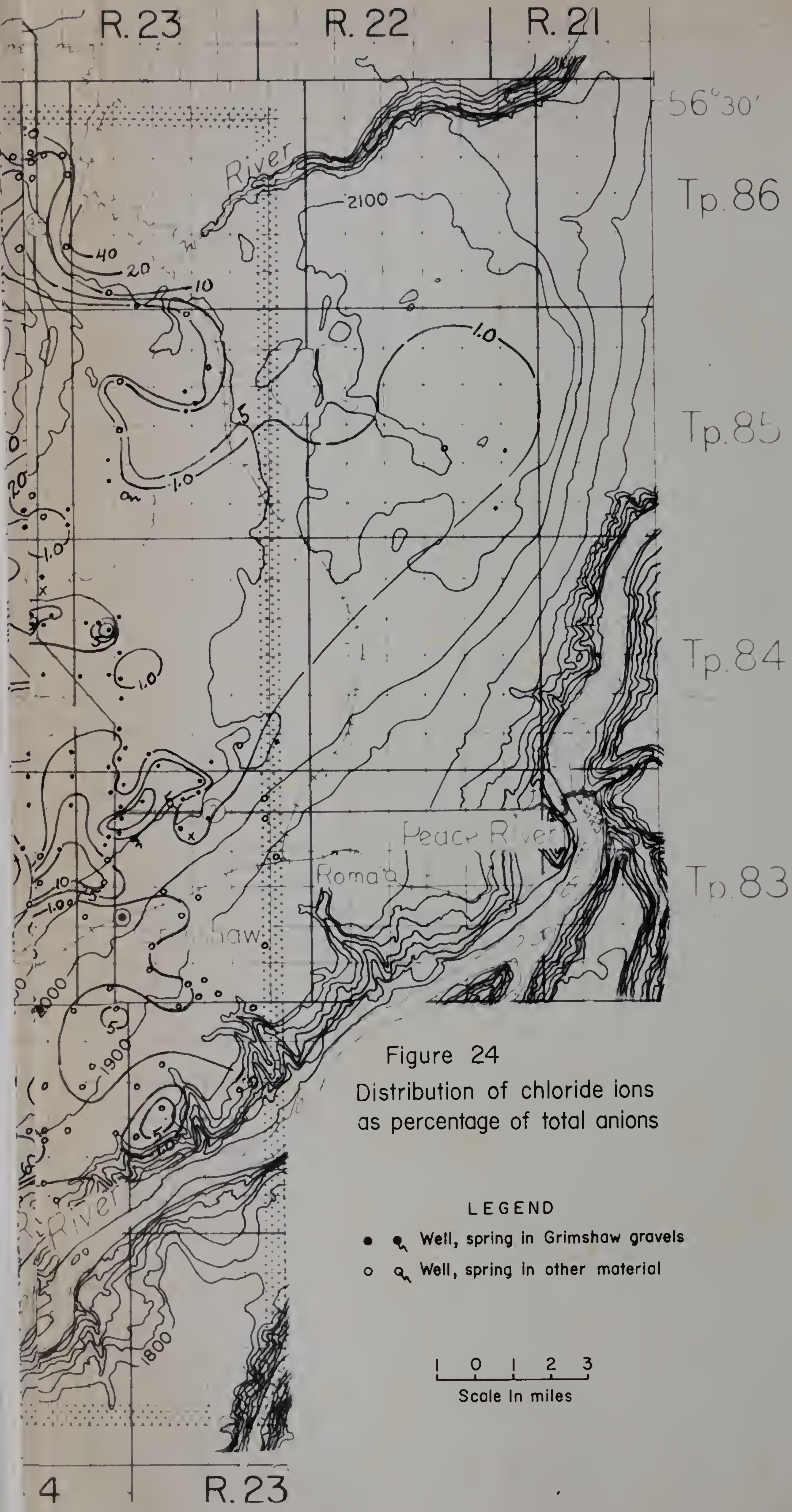


Figure 24
Distribution of chloride ions as percentage of total anions

Figure 25

Distribution of nitrate anions, in parts per million

LEGEND

- Well, spring in Grimshaw gravels
- Well, spring in other material

0 1 2 3
Scale in miles

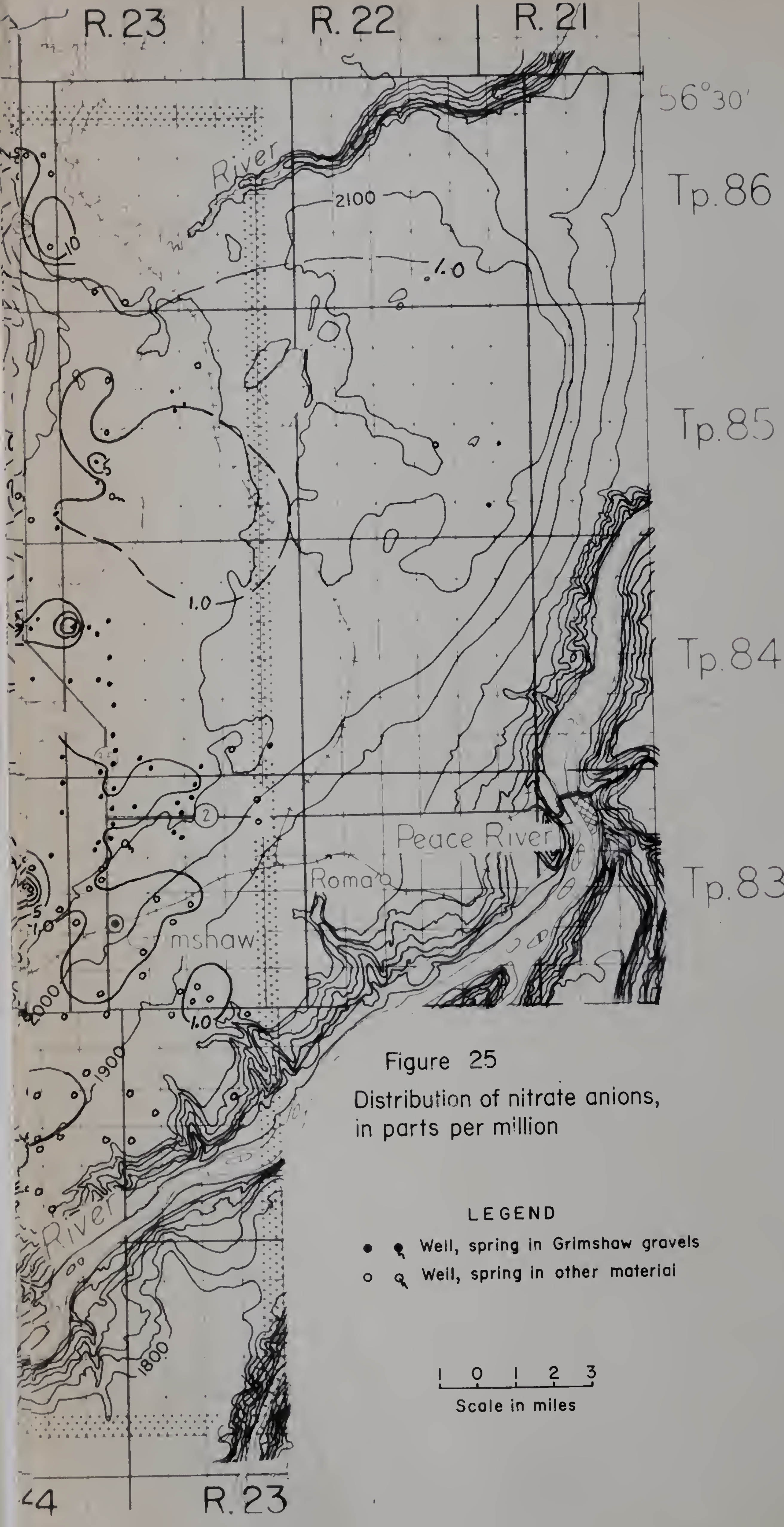


Figure 25
Distribution of nitrate anions, in parts per million

Figure 26

Distribution of calcium and magnesium ions, as percentage of total cations

LEGEND

- Well, spring in Grimshaw gravels
- Well, spring in other material

1 0 1 2 3
Scale in miles

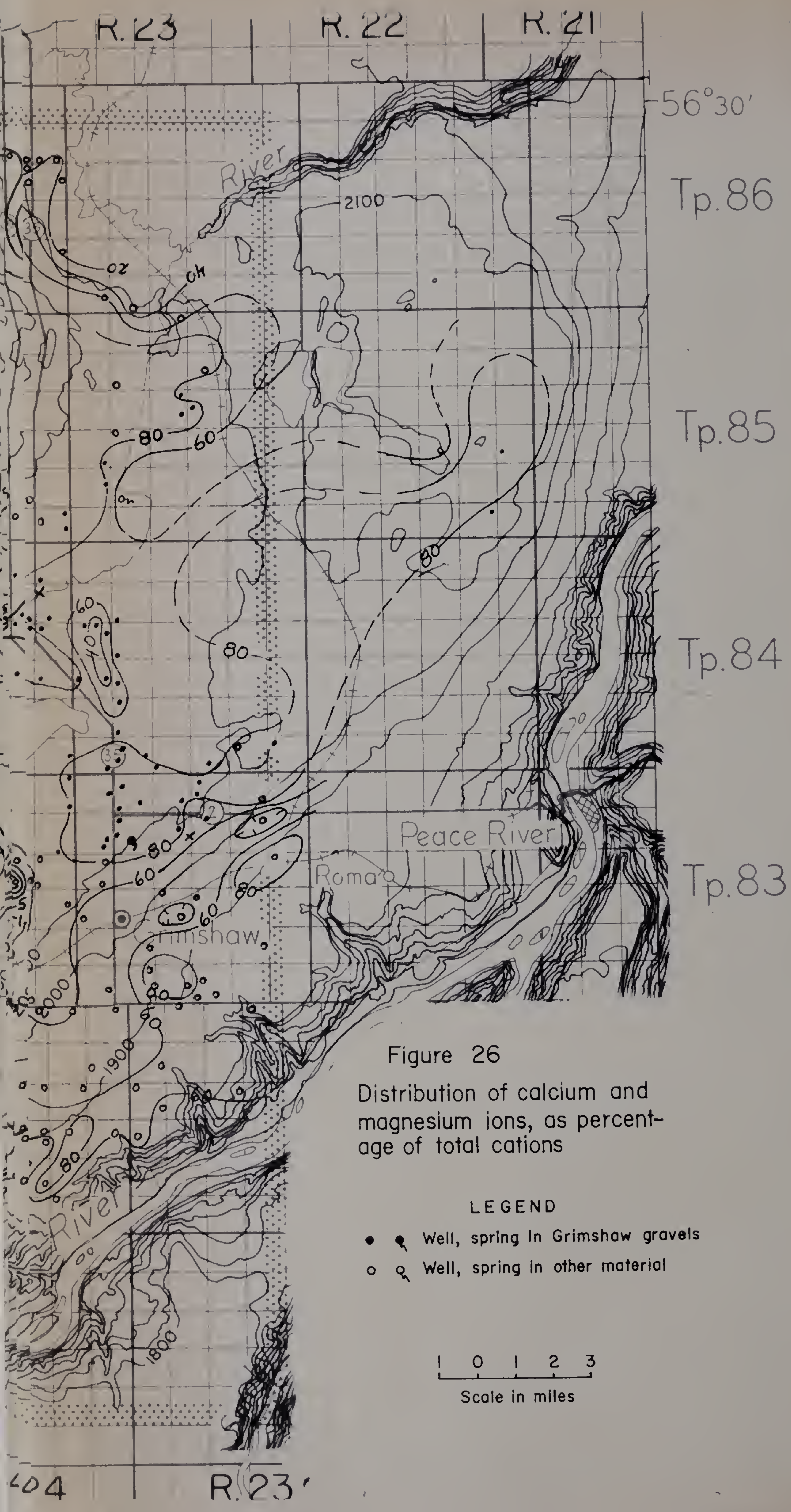


Figure 26
Distribution of calcium and magnesium ions, as percentage of total cations

Figure 27
Variation in the calcium: magnesium ratio

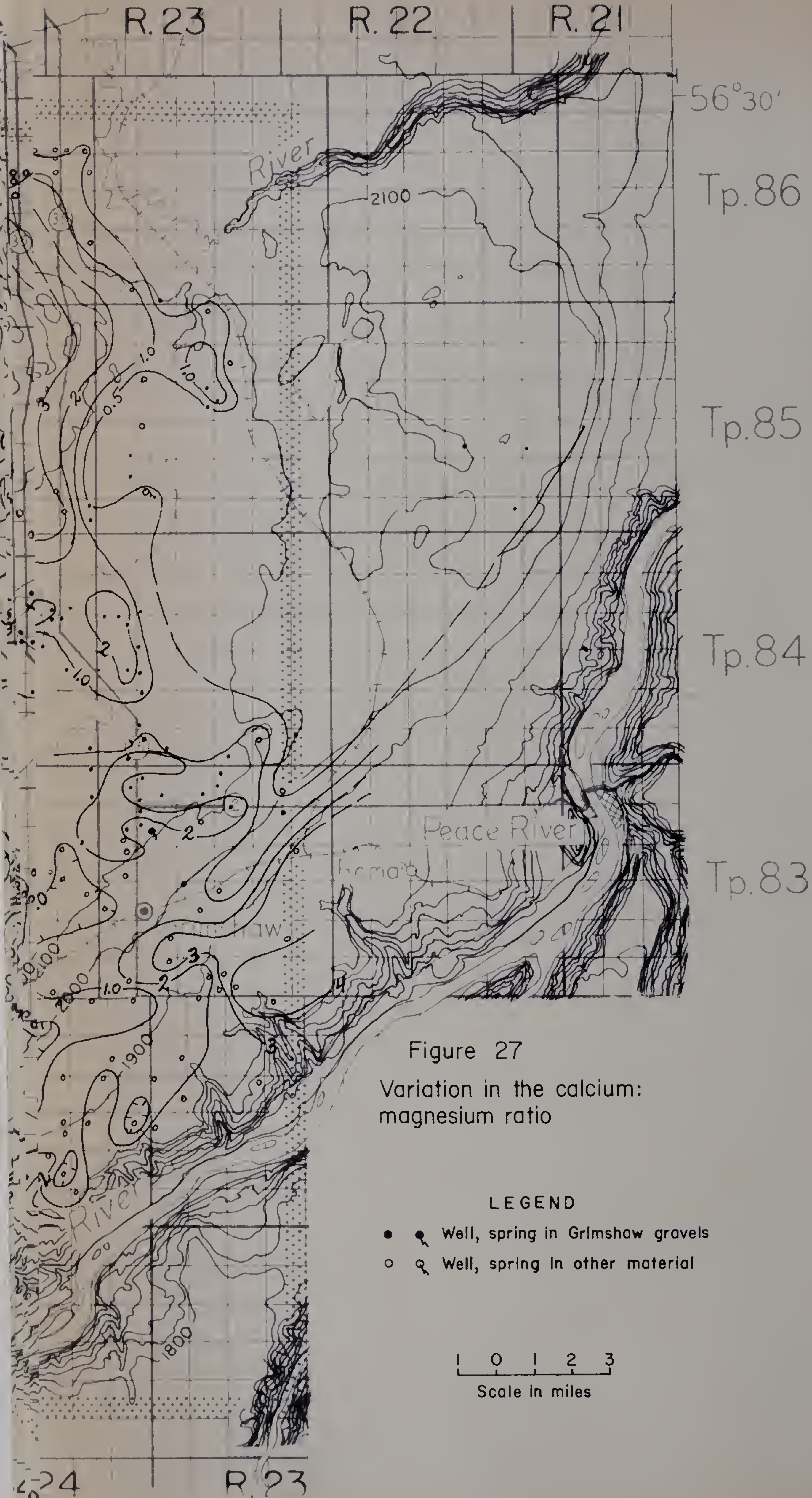


Figure 27

Variation in the calcium: magnesium ratio

Figure 28

Distribution of iron, in parts per million

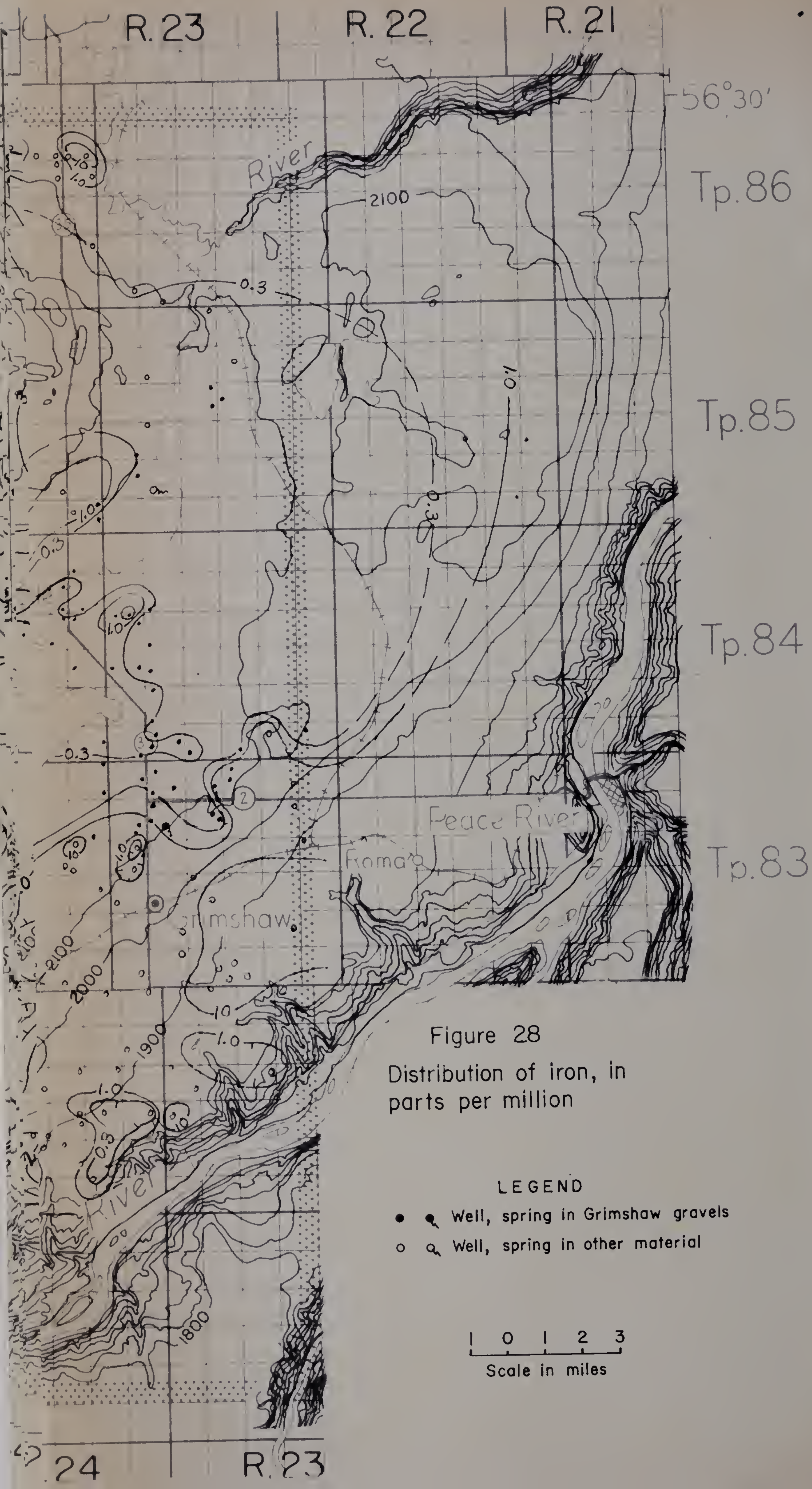


Figure 28
Distribution of iron, in parts per million

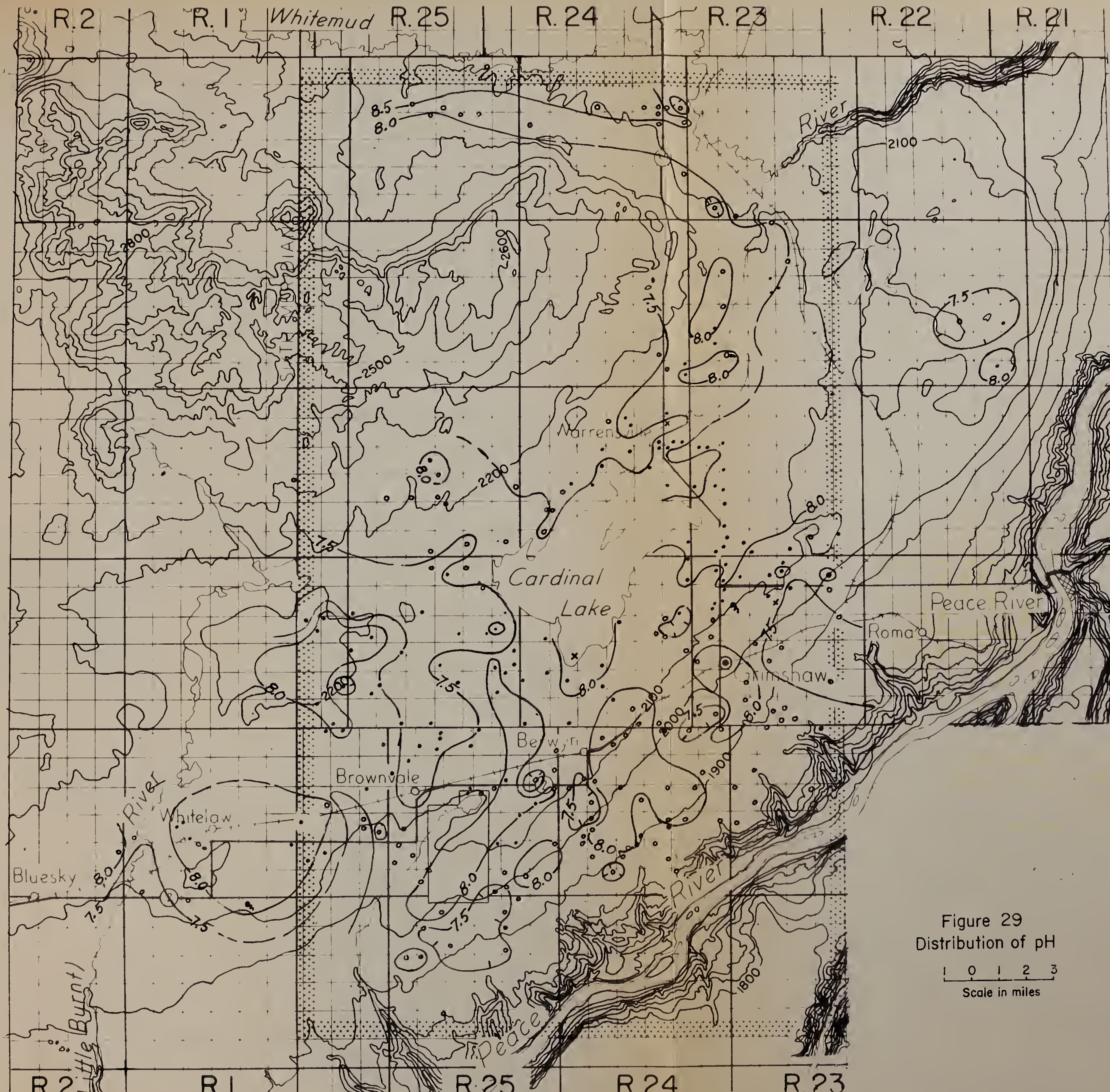


Figure 29
Distribution of pH

Figure 29
Distribution of pH

1 0 1 2 3
Scale in miles

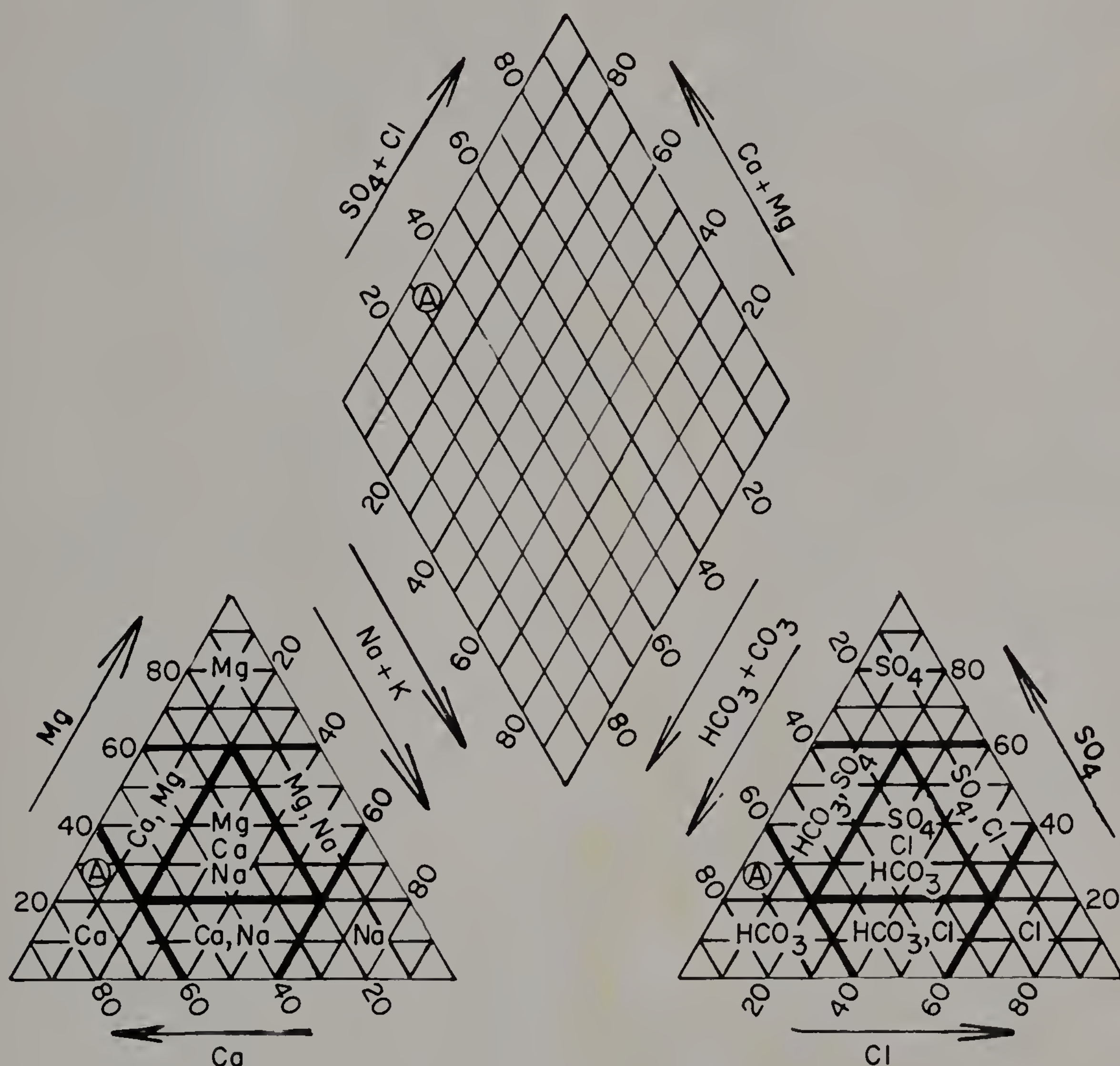


Figure 30

Water classification based on the percentage of equivalents per million (After Davis & De Weist, 1966, p. 119)

Point Ⓐ represents calcium bicarbonate water

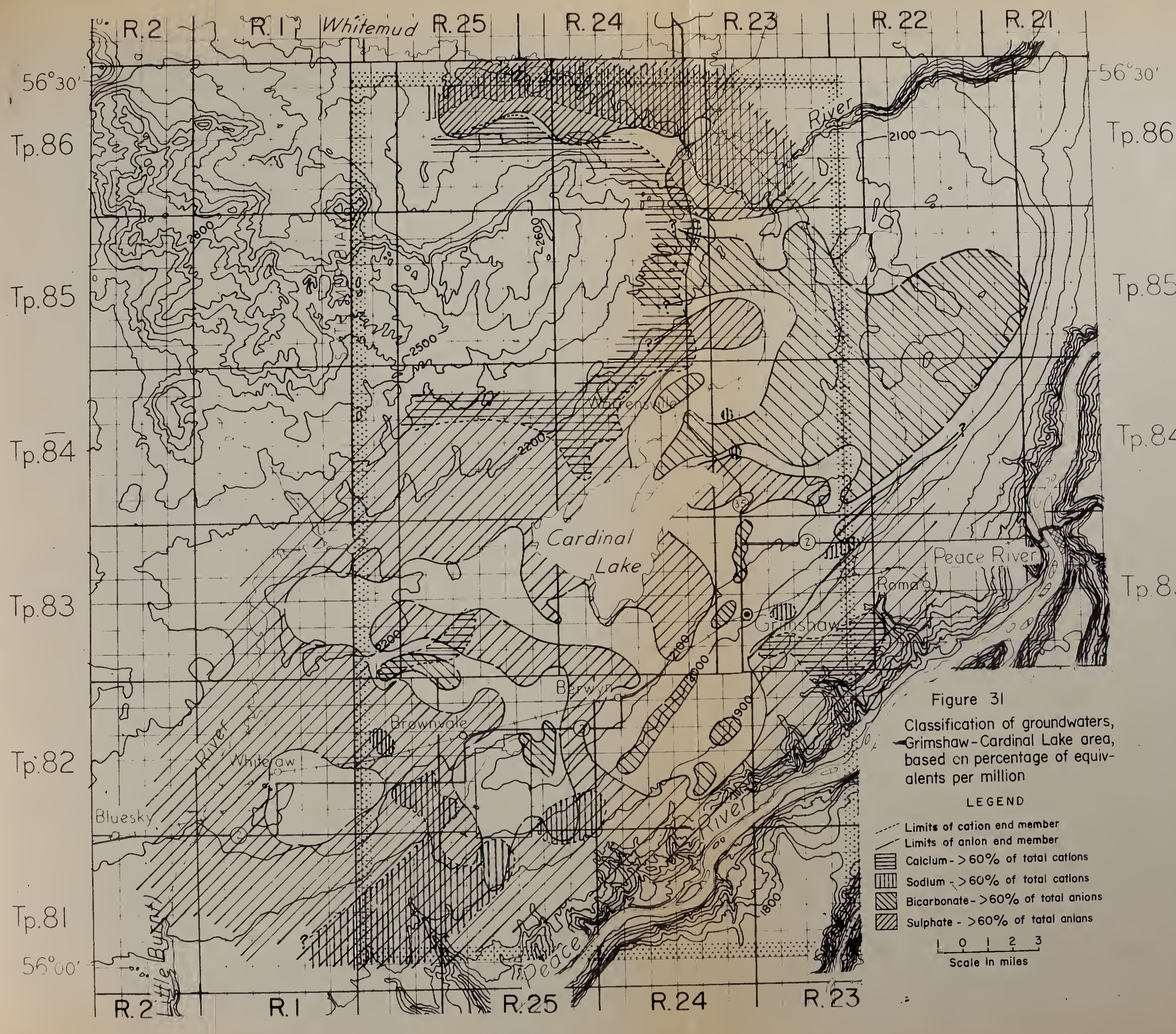


Figure 31

Classification of groundwaters, Grimshaw-Cardinal Lake area, based on percentage of equivalents per million

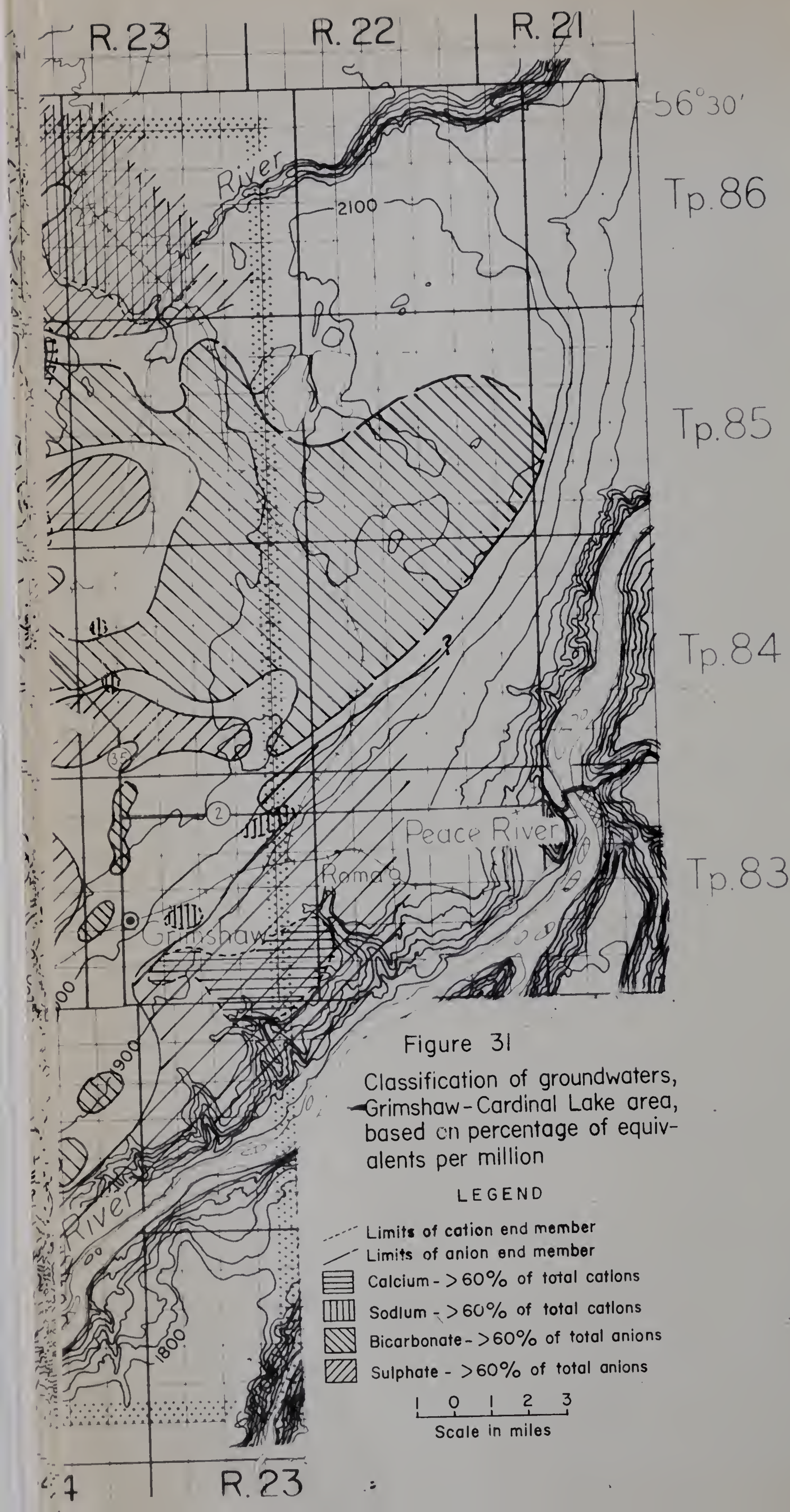


Figure 31

Classification of groundwaters, Grimshaw-Cardinal Lake area, based on percentage of equivalents per million

Classification of Water in Grimshaw-Cardinal Lake Area

The groundwaters of the Grimshaw-Cardinal Lake area have been classified as to type by the method presented by Davis and DeWeist (1966, p. 119). This method is based on the percentage of equivalents per million of the anions and cations (Fig. 30), the same as that used in the construction of the cation and anion percentage maps just presented (Figs. 23, 24, and 26). The end members of the classification presented by Davis and DeWeist (1966, p. 119) are cross-hatched on the accompanying map (Fig. 31). Of the anions, the sulphate end member is dominant and occurs in both recharge and discharge areas, and the chloride end member is not present. Of the cations, the calcium end member is found mainly in recharge areas, the sodium end member mainly in discharge areas (and in flowing wells), and the magnesium end member is not present.

Anion end members occur together with cation end members as follows: sodium sulphate waters in discharge areas, calcium bicarbonate waters mainly in recharge areas, calcium sulphate waters in some areas, and sodium bicarbonate waters do not occur. Intermediate type waters, mainly the calcium, magnesium, bicarbonate type, and the calcium, magnesium, bicarbonate, sulphate type, are the commonest waters in the Grimshaw gravels.

Aquifer Testing

Introduction

The hydraulic properties of aquifers which most aquifer tests are designed to evaluate are the coefficients of permeability or transmissibility and the coefficient of storage. If these properties are known, well yields to be expected over any desired time interval can be calculated. Walton (1962, p. 3) outlined these

properties as follows:

"The rate of flow of groundwater in response to a given hydraulic gradient is dependent upon the permeability of the aquifer. The field coefficient of permeability P is defined as the rate or flow of water, in gallons per day, through a cross-sectional area of one square foot of the aquifer under a hydraulic gradient of one foot per foot at the prevailing temperature of the water. A related term, the coefficient of transmissibility T, indicates the capacity of an aquifer as a whole to transmit water and is equal to the coefficient of permeability multiplied by the saturated thickness of the aquifer m, in feet. The coefficient of transmissibility is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer one foot wide and extending the full saturated thickness under a hydraulic gradient of 1 foot per foot at the prevailing temperature of the water.

"The storage properties of an aquifer are expressed by its coefficient of storage S, which is defined as the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component head normal to that surface. Under artesian conditions, when the piezometric surface is lowered by pumping, water is derived from storage by the compaction of the aquifer and its associated beds and by expansion of the water itself, while the interstices remain saturated. Under water-table conditions, when the water table is lowered by pumping, groundwater is derived from storage mainly by the gravity drainage of the interstices in the portion of the aquifer unwatered by the pumping."

A number of tests for aquifer yield were conducted. A two hour bail test, followed by a two hour period of recovery was the principal test employed to obtain an initial evaluation of the well yield to be expected. Seven bail tests were conducted, one on a Dunvegan sandstone aquifer, one on an intermediate level gravel aquifer (both artesian cases), and five on the Grimshaw gravels. Two pumping tests were carried out, one for a two hour period and the other for a four day period.

A graphical solution devised by Cooper and Jacob (1946) has been used in the analysis of measurements made in the pumped or bailed well. This method is based on a modification made by Cooper and Jacob on the nonleaky artesian formula introduced by Theis (1935). Values of transmissibility are readily calculated by this method in both artesian and water-table cases, provided adjustments are made for barometric efficiency (in artesian cases), for effects of dewatering due to gravity drainage (in water-table cases), and for partial penetration effects.

The coefficient of storage can be calculated by this method with a fair degree of accuracy in the case of observation wells which are sufficiently distant from the pumping well, but cannot be determined with any degree of assurance for pumping or bailed wells. This is because the effective radius of the pumped or bailed well is not usually known, and drawdowns are often affected by well losses which are difficult to determine precisely (Walton, 1962, p. 9).

<u>Pump Tests</u>

A 4-day pump test was conducted in January, 1967 on a screened well completed in the Grimshaw gravels. Two observation wells were used during the test. The details of well construction and lithology are shown on figure 32.

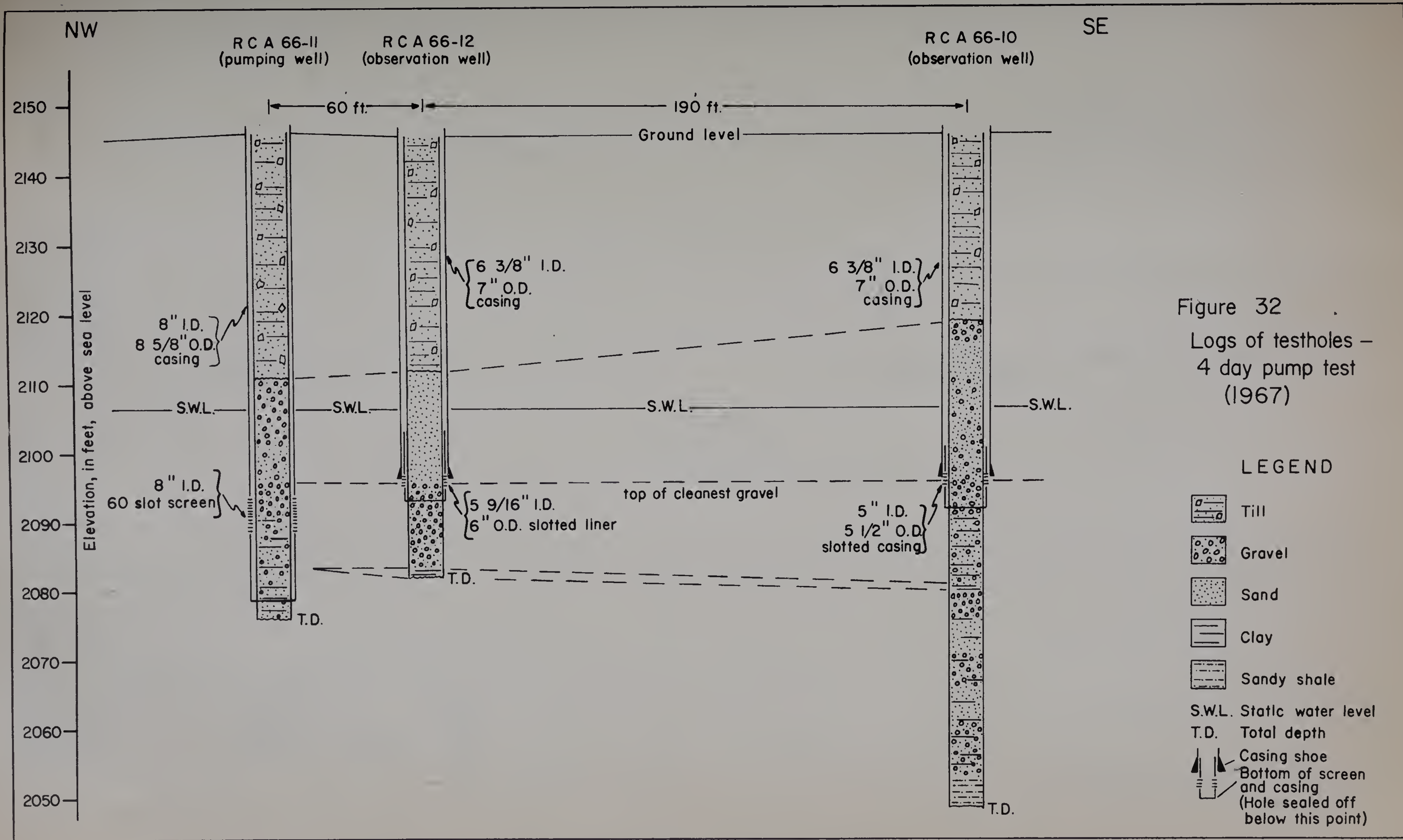


Figure 32

Logs of testholes – 4 day pump test (1967)

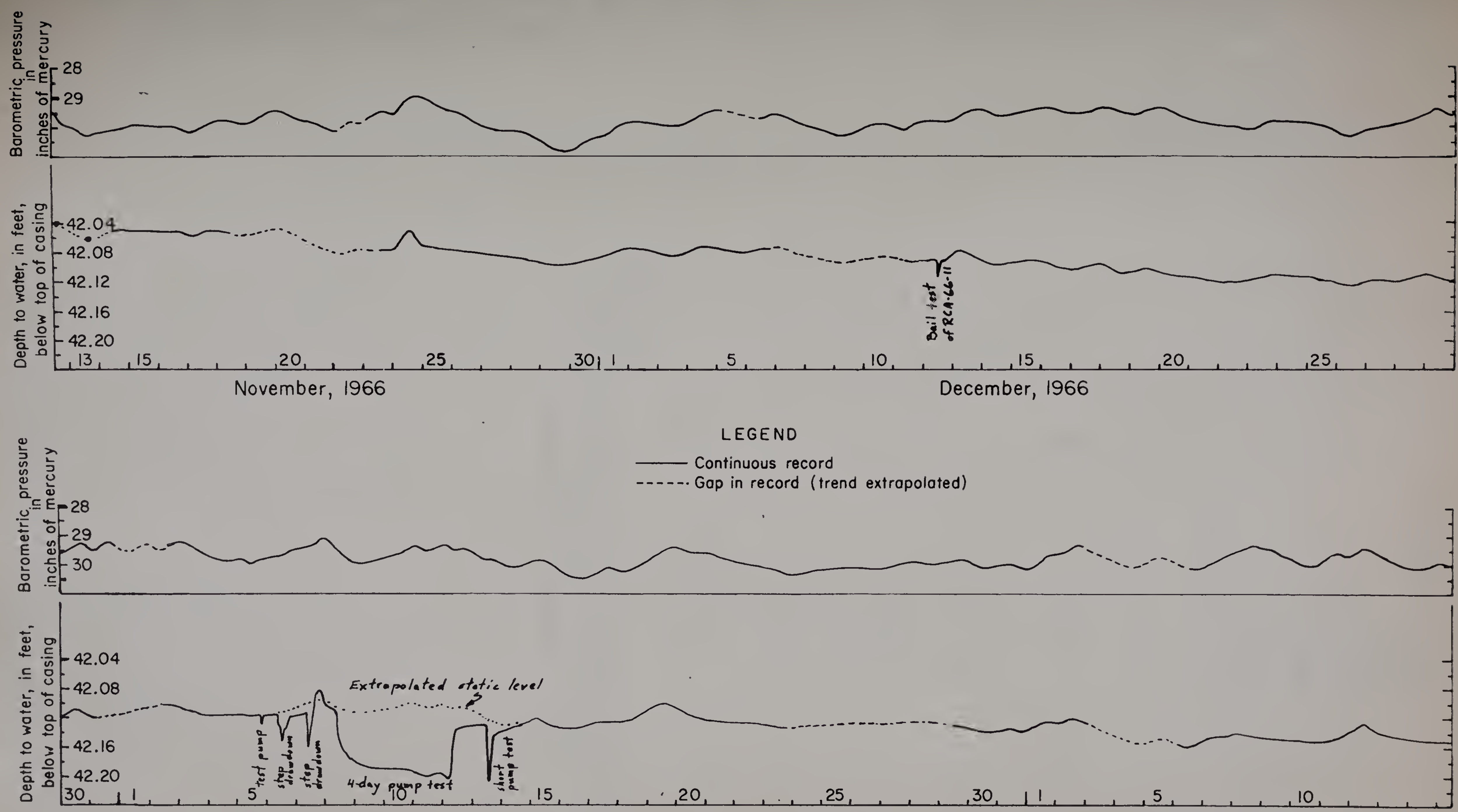


Figure 33
Relationship between barometric pressure fluctuations and water level fluctuations in well RCA 66-10 (I)
November 12, 1966 to February 15, 1967

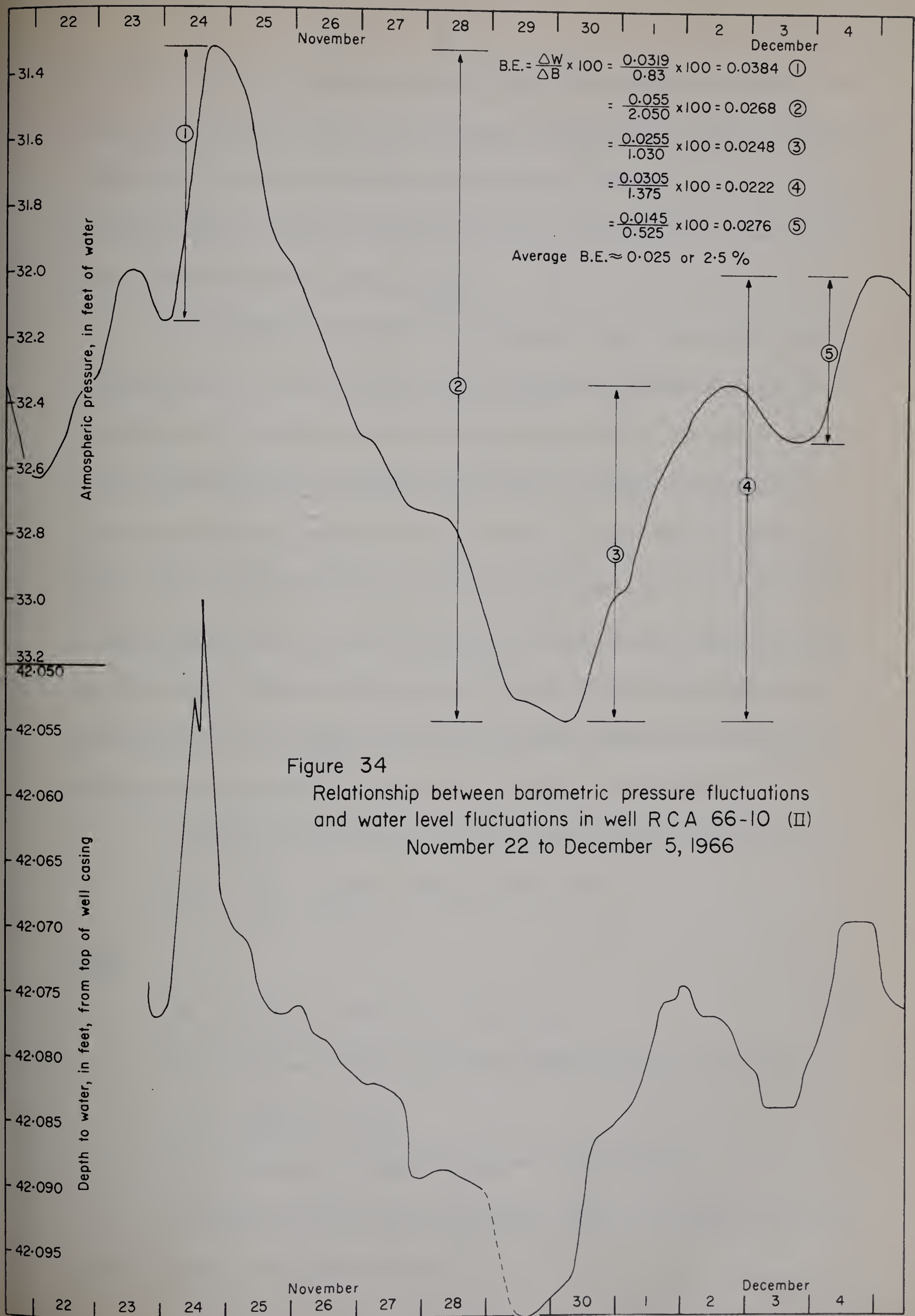


Figure 34
Relationship between barometric pressure fluctuations and water level fluctuations in well RCA 66-10 (II)
November 22 to December 5, 1966

Drawdown and recovery measurements were taken in the pumped well using a combination of an electrical tape and a steel tape. The observation wells were equipped with automatic water-level recorders. Observations on the static water level in one well were made for almost two months prior to the start of pumping and were carried on for 1 1/2 months after pumping stopped.

A correlation was found to exist between changes in barometric pressure and fluctuations in water level (Fig. 33). The barometric efficiency was found to vary between 1.7 and 5 per cent but averaged about 2 1/2%. The normal method used to determine barometric efficiency is to plot, on arithmetic scale, water-level versus barometric pressure and to draw the best straight line through the plotted points. This method did not work well in this case because of a very wide scattering of plotted points, due to the wide variance in efficiency and to a generally declining static level. Barometric efficiency was therefore determined by direct comparison of static level changes and barometric pressure changes and calculation of efficiency between extremes of water level at different times (Fig. 34).

The barometric efficiency was calculated by the use of the formula

$$BE = \frac{W}{B} \times 100 \qquad \text{(Walton, 1962, p. 4)}$$

where

BE = barometric efficiency, in per cent;

W = change in water level resulting from a change in atmospheric pressure, in feet;

B = change in atmospheric pressure in feet of water.

As temperatures were below freezing throughout the drilling and testing period, recharge through precipitation did not occur.

Analysis of drawdown in observation wells

Analysis of the drawdown measurements in the observation wells was made by the type-curve graphical method of Prickett (1965), based on the theory developed by Boulton (1963) which describes the nonequilibrium time-drawdown relationships under pumping from a water-table aquifer. The observed drawdowns in the observation wells were small enough that adjustment for the effects of dewatering were not needed. Corrections for barometric pressure effects were required after the first two hours of pumping.

The Prickett (1965) method of solution utilizes a series of compound-type curves. These each consist of two portions: 1) a "Type A" curve which is essentially the same as the set of leaky artesian type curves of Walton (1960); and 2) the "Type Y" curve. The "Type Y" curves become asymptotic to and merge into the nonequilibrium type curve. The "Type A" curve portion is used in the analysis of early time-drawdown observations and the "Type Y" curve for late time-drawdown observations.

The formulae used in the analysis of the data are given below. (For the derivations of the formulae, reference is made to Prickett (1965).):

$$T = \frac{114.6QW(u_{AY}\ r/D)}{s}$$

$$S = \frac{Tu_A t}{2242r^2}$$

$$S_Y = \frac{Tu_Y t}{2242r^2}$$

where

T = coefficient of transmissibility, in imperial gallons per day per foot;

Q = discharge rate, in imperial gallons per minute;

$W(u_{AY}, r/D)$ = the "well function for water-table aquifers" for the particular case when n tends to infinity and $n = \frac{(S + Sy)}{S}$;

s = drawdown in observation well, in feet;

S = volume of water instantaneously released from storage per unit drawdown per unit horizontal area, which is the effective early-time coefficient of storage;

Sy = total volume of delayed yield from storage per unit drawdown per unit horizontal area (commonly referred to as the specific yield);

t = time after pumping started, in minutes;

r = distance from pumped well to observation well, in feet;

$u_A = \frac{2242 r^2 S}{Tt}$;

$D = \sqrt{\frac{T}{\alpha Sy}}$;

$u_Y = \frac{2242 r^2 S_Y}{Tt}$;

$r/D = \frac{104 r}{T/\alpha Sy}$; and

$\alpha = \frac{(r/D)^2 Y u_Y}{4t}$ = reciprocal of "delay index" in minutes.

In the analysis of this pump test by the Prickett method, it was found that the solution for early time-drawdown data gave low values for transmissibility.

It is thought that this was due mainly to the effects of partial penetration.* The transmissibility obtained from this early segment of the curve was 16,370 igpd/ft in the near observation well and 141,800 igpd/ft in the far observation well, indicating that for fractional penetration of 0.02, partial penetration effects were still strongly felt as far as 250 feet from the observation well. With increased time of pumping the effects of partial penetration, although still present, interfered less and less with the interpretation of test results and in this particular case were considered to be negligible in the late time-drawdown analysis. A transmissibility of 327,400 igpd/ft for the near observation well and of 382,000 igpd/ft for the far observation well was obtained from the late time-drawdown analysis. The solutions by the Prickett method of analysis for the two observation wells are shown on figures 35 and 36.

The values that were obtained from the late time-drawdown analysis for the storage coefficient, S, in the two wells were quite different; 0.019 in the near well and 0.32 in the far well. This divergence is due to the positioning of the plotted points well back near the straight line portion of the nonequilibrium type curve in the one case, and near the early, curved portion of the curve in the other (Figs. 35 and 36). This divergence in positioning makes a large difference in the S value which is consequently obtained, but has much less effect on the transmissibility value.

---

*The Grimshaw gravels at this locality have a saturated thickness of 52 feet. The pumping well was completed with 5 feet of screen near the top of the water-saturated portion (ie. fractional penetration was 0.10); the observation wells were completed with 2 feet of slotted casing near the top of the water-bearing portion (fractional penetration of 0.02).

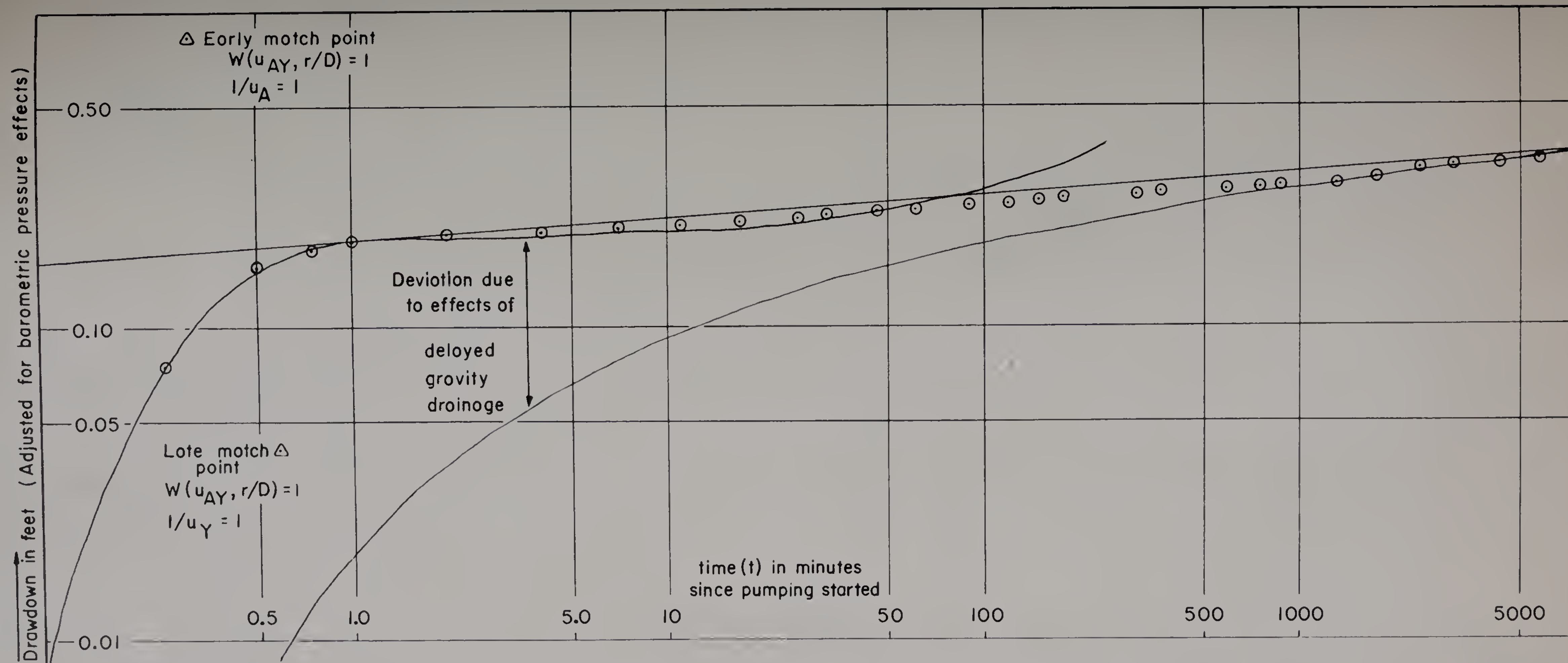


Figure 35 Time - drawdown graph, January 1967 pump test, observation well #1

Observation well (RCA 66-12) 60 feet from pumping well (RCA 66-11). Prickett, 1965, method of solution

Early segment of curve

$$T = \frac{114.6\,Q\,W(u_{AY}, r/D)}{s} = \frac{114.6 \times 123}{0.84} = 16{,}770 \text{ igpd/ft.}$$

$$S = \frac{T u_A t}{2242\, r^2} = \frac{16{,}770 \times 0.3}{2242 \times 60 \times 60} = 6.1 \times 10^{-4}$$

Late segment of curve

$$T = \frac{114.6\,Q\,W(u_{AY}, r/D)}{s} = \frac{114.6 \times 123}{0.043} = 335{,}600 \text{ igpd/ft.}$$

$$S_Y = \frac{T u_Y t}{2242\, r^2} = \frac{335{,}600 \times 0.57}{2242 \times 60 \times 60} = 2.4 \times 10^{-2}$$

r = 60 feet
m = 52 feet (portiol penetrotion = 0.04)
Q = 123 igpm
Partial penetrotion correction not needed
Correction for decrease in oquifer thickness not required

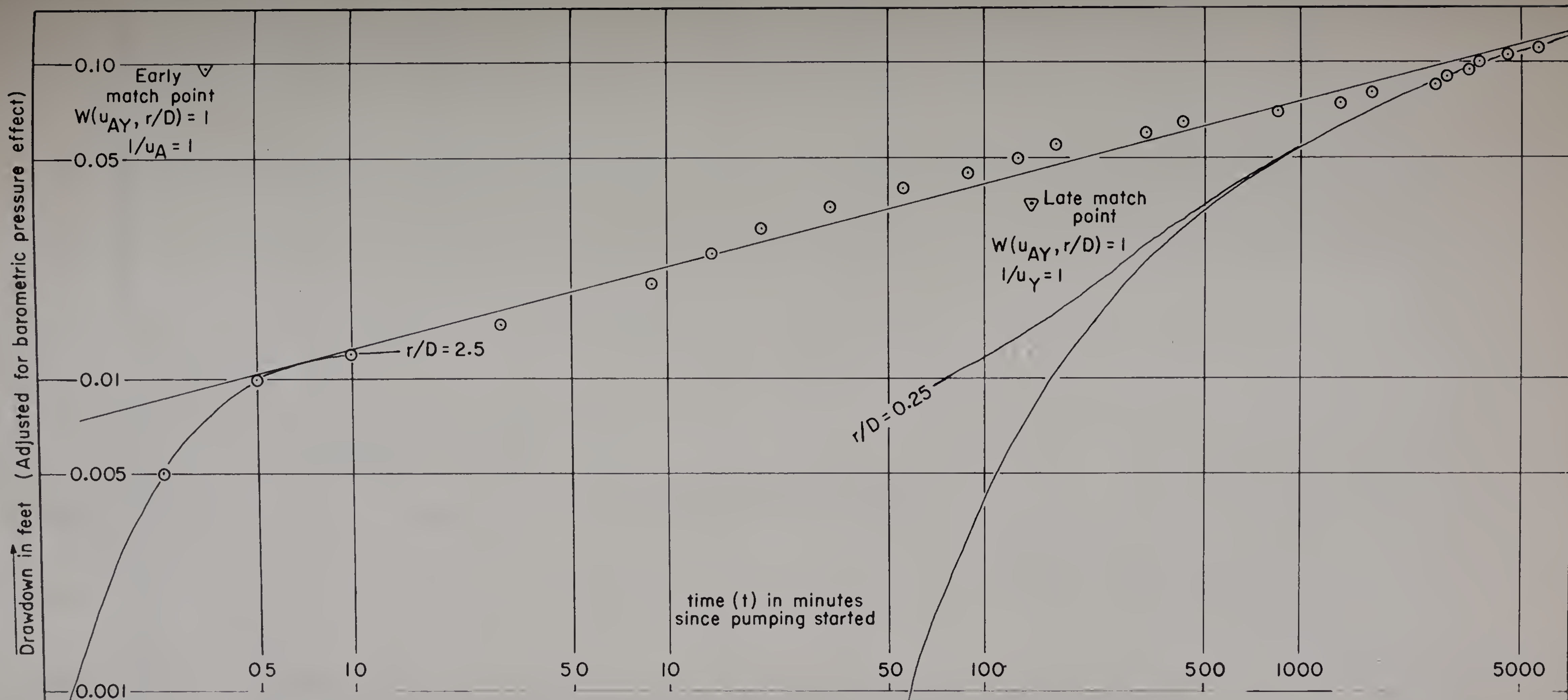


Figure 36 Time-drawdown graph, January 1967 pump test, observation well #2

Observation well (RCA 66-10) 250 feet from pumping well (RCA 66-11). Prickett, 1965, method of solution

Early segment of curve

$$T = \frac{114.6\,Q\,W(u_{AY}, r/D)}{s} = \frac{114.6 \times 123}{0.097} = 145{,}300 \text{ igpd/ft.}$$

$$S = \frac{T u_A t}{2242\, r^2} = \frac{145{,}300 \times 0.35}{2242 \times 250 \times 250} = 3.61 \times 10^{-4}$$

r = 250 feet
m = 52 feet (partial penetration = 0.04)
Q = 123 igpm

Late segment of curve

$$T = \frac{114.6\,Q\,W(u_{AY}, r/D)}{s} = \frac{114.6 \times 123}{0.036} = 391{,}000 \text{ igpd/ft.}$$

$$S_Y = \frac{T u_Y t}{2242\, r^2} = \frac{391{,}000 \times 140}{2242 \times 250 \times 250} = 0.39$$

Partial penetration correction not required
Adjustment for dewatering, e.g. when $s = 0.1$, $s' = 0.1 - \frac{0.1}{100} = 0.09999 \approx 0.1'$
∴ Correction for decrease in aquifer thickness, not required

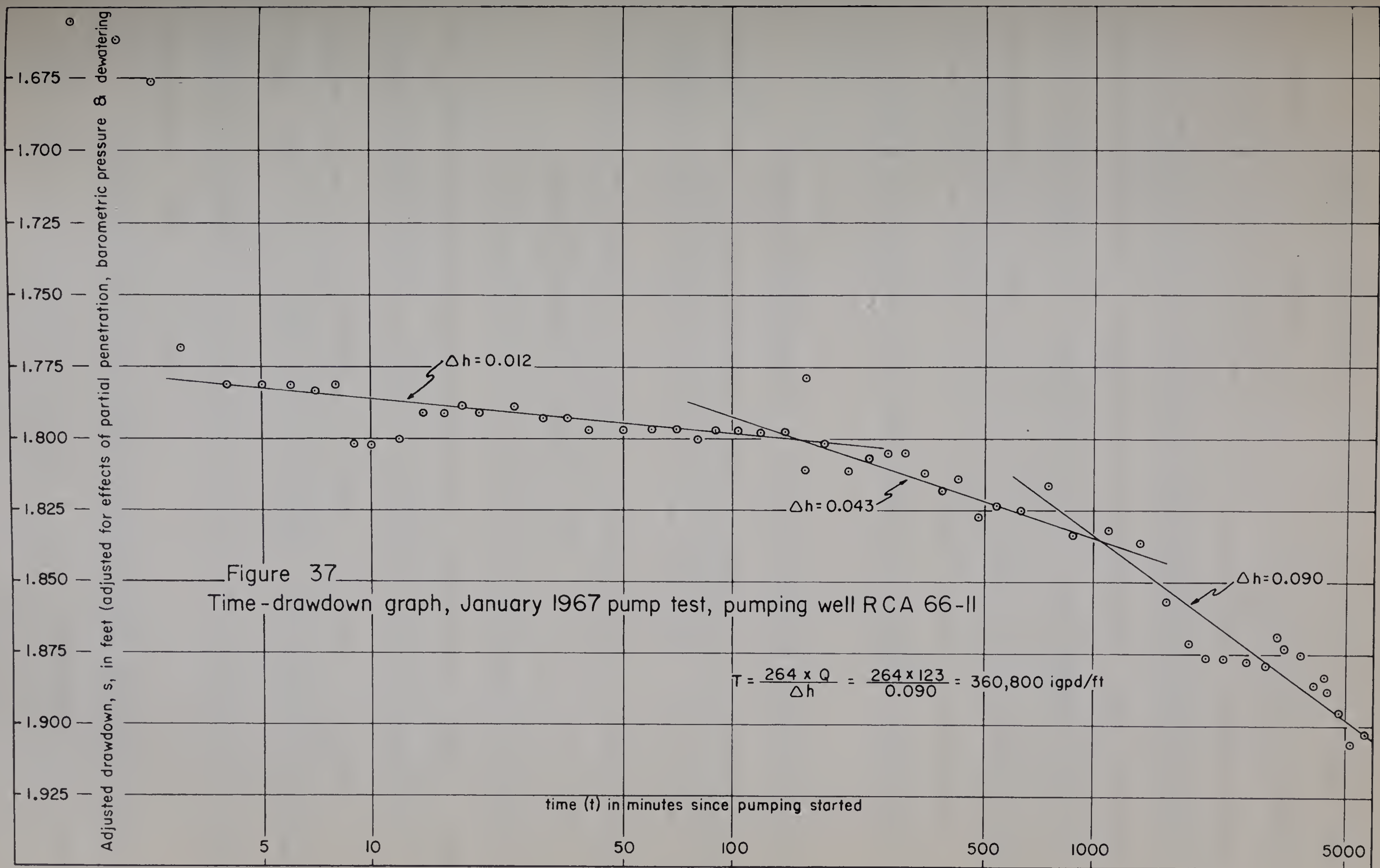


Figure 37
Time-drawdown graph, January 1967 pump test, pumping well RCA 66-II
Adjusted drawdown, s, in feet (adjusted for effects of partial penetration, barometric pressure & dewatering
time (t) in minutes since pumping started
Δh = 0.012
Δh = 0.043
Δh = 0.090
T = 264 x Q / Δh = 264 x 123 / 0.090 = 360,800 igpd/ft
1.675
1.700
1.725
1.750
1.775
1.800
1.825
1.850
1.875
1.900
1.925
5
10
50
100
500
1000
5000

Another critical factor in the proper interpretation of test data is that while the barometric efficiency averages 2.5%, it can vary greatly, values from 1.7 to 5% having been calculated. With the extremely low drawdowns obtained in the observation wells, an error in the determination of this value can make a significant difference in the positioning of the plotted point. Again, this will have its major effect on the calculated value of S. Eckis (1934) has determined from laboratory investigations that for material ranging from coarse sand to medium gravel (maximum 10% grain size from 1 to 32 mm) the specific yield, which in water-table cases is equal to the storage coefficient, ranges from about 20% to 32%.

Prickett (1965) introduced a parameter called the delay index, which is related to the time which must elapse during a pumping test in order for the effects of delayed gravity drainage to dissipate in observation wells. This parameter could not be calculated because of the effects of partial penetration on early drawdowns.

Analysis of drawdown in pumping well

The analysis of drawdown measurements in the pumping well (Table 4, Fig. 37) was made by the graphical method of Cooper and Jacob (1946). In addition to the barometric pressure correction, a correction for partial penetration was applied as given by Butler (1957, p. 157-164) from equations developed by Muskat (1937), Kozeny (1933), and Jacob (1945). These equations were derived for partial penetration in confined aquifer cases but can be adapted to free aquifer cases (Butler, 1957, p. 163-164).

The formula used in computing transmissibility by this method follows. For the derivation of the formula, reference is made to Cooper and Jacob (1946):

Table 4

Drawdown in Pumping Well - Pump Test, January, 1967

Date	Time	Time, t since pumping started	Depth to water (feet)	Observed drawdown spp (feet)	Drawdown corrected for barometric pressure, sb (feet)	Drawdown corrected for partial penetration (feet)	Drawdown corrected for dewatering s' (feet)	Pumping rate Q (igpm)
Jan. 8/67	9.00 a.m.		41.58	0(S.W.L.)				
	9.45		41.58	0(S.W.L.)				
	10.00.30	1/2	49.40	7.82		1.720	1.691	
	10.01	1	49.42	7.84		1.725	1.696	117
	10.01.30	1 1/2	49.23	7.65		1.683	1.655	
	10.02	2	49.26	7.68		1.690	1.662	117
	10.02.30	2 1/2	49.33	7.75		1.705	1.676	
	10.03	3 3	49.76	8.18		1.800	1.768	112
	10.04	4 4	49.82	8.24		1.813	1.781	
	10.05	5	49.82	8.24		1.813	1.781	122
	10.06	6	49.82	8.24		1.813	1.781	
	10.07	7	49.83	8.25		1.815	1.783	123
	10.08	8	49.82	8.24		1.813	1.781	
	10.09	9	49.92	8.34		1.835	1.802	
	10.10	10	49.92	8.34		1.835	1.802	123
	10.12	12	49.91	8.33		1.833	1.800	
	10.14	14	49.87	8.29		1.824	1.791	123
	10.16	16	49.87	8.29		1.824	1.791	
	10.18	18	49.86	8.28		1.822	1.789	
	10.20	20	49.87	8.29		1.824	1.791	123
	10.25	25	49.86	8.28		1.822	1.789	
	10.30	30	49.88	8.30		1.826	1.793	122
	10.35	35	49.88	8.30		1.826	1.793	

Date	Time	Time, t since pumping started	Depth to water (feet)	Observed drawdown spp (feet)	Drawdown corrected for barometric pressure, sb (feet)	Drawdown corrected for partial penetration s. (feet)	Drawdown corrected for dewatering s' (feet)	Pumping rate Q (igpm)
Jan. 8/67	10.40 a.m.	40	49.90	8.32		1.830	1.797	122
	10.50	50	49.90	8.32		1.830	1.797	
	11.00	60	49.90	8.32		1.830	1.797	123
	11.10	70	49.90	8.32		1.830	1.797	
	11.20	80	49.91	8.33		1.833	1.800	124
	11.30	90	49.90	8.32		1.830	1.797	123
	11.45	105	49.90	8.32		1.830	1.797	123
	12.00 Noon	120	49.905	8.325		1.831	1.798	123
	12.20	140	49.905	8.325		1.831	1.798	122
	12.40	160	49.81	8.23		1.811	1.779	122
	1.00 p.m.	180	49.915	8.335		1.834	1.801	122
	1.30	210	49.96	8.38		1.844	1.811	122
	2.00	240	49.95	8.37		1.841	1.807	121
	2.30	270	49.94	8.36		1.839	1.805	121
	3.00	300	49.94	8.36		1.839	1.805	124
	3.40	340	49.97	8.39		1.846	1.812	123
	4.20	380	50.00	8.42		1.852	1.818	124
	5.00	420	49.98	8.40		1.848	1.814	124
	6.00	480	50.04	8.46		1.861	1.827	123
	7.00	540	50.02	8.44		1.857	1.823	123
	8.30	630	50.03	8.45		1.859	1.825	123
	10.30 p.m.	750	49.99	8.41		1.850	1.816	123
Jan. 9/67	12.30 Midn.	870	50.07	8.49		1.868	1.834	124
	4.30 a.m.	1110	50.06	8.48		1.866	1.832	124
	8.30 a.m.	1350	50.08	8.50		1.870	1.836	124
	12.30 Noon	1590	50.18	8.60		1.892	1.857	123

Date	Time	Time, t since pumping started	Depth to water (feet)	Observed drawdown spp (feet)	Drawdown corrected for barometric pressure, sb (feet)	Drawdown corrected for partial penetration s (feet)	Drawdown corrected for dewatering s' (feet)	Pumping rate Q (igpm)
Jan. 9/67	4.30 p.m.	1830	50.25	8.67		1.907	1.871	123
	8.30 p.m.	2070	50.27	8.69		1.912	1.876	124
Jan. 10/67	12.30 Midn.	2310	50.27	8.69		1.912	1.876	123
	6.30 a.m.	2670	50.28	8.70		1.914	1.878	123
	12.30 Noon	3030	50.28	8.70	8.705	1.915	1.879	124
	4.30 p.m.	3250	50.23	8.65	8.66	1.905	1.869	123
	6.30 p.m.	3390	50.25	8.67	8.68	1.909	1.873	
Jan. 11/67	12.30 Midn.	3750	50.28	8.68	8.69	1.911	1.875	124
	6.30 a.m.	4110	50.31	8.73	8.735	1.922	1.886	123
	11.15 a.m.	4395	50.30	8.72	8.725	1.919	1.883	
	12.30 Noon	4470	50.32	8.74	8.745	1.924	1.888	124
	6.30 p.m.	4830	50.35	8.77	8.78	1.932	1.895	125
Jan. 12/67	12.30 Midn.	5190	50.40	8.82	8.83	1.943	1.906	124
	9.00 a.m.	5700	50.40	8.82	8.82	1.940	1.903	
	9.50 a.m.	5750	50.40	8.82	8.82	1.940	1.903	125
	10.00 a.m.	Shut off pump. Start recovery measurements.						

$$T = \frac{264Q}{s}$$

where s = drawdown difference in feet per log cycle. A transmissibility value of 352,000 igpd/ft was obtained. This compares favorably with the values obtained in the observation wells. For reasons outlined on page 75, a value for the storage coefficient, S, cannot be calculated by this method.

The test site was located so that boundary effects could be avoided and none was apparent during the duration of the test. The nearest barrier boundary as shown in enclosure 2 lies approximately one mile north of the test site, while a recharge boundary is provided by the waters of Cardinal Lake 1 1/2 miles to the northwest.

The recovery measurements, when analysed by this method, yield a value of transmissibility 6 to 7 times that obtained from the drawdown data. Approximately the same value is obtained by using the early time-drawdown data. This value is considered to be overly optimistic and has not been used here.

Calculation of safe yield

A calculation of the safe yield from a single well for a prolonged period of pumping may be obtained by the extension of the drawdown trend in the pumping well to the desired time interval. The trend of the drawdown (Fig. 37) is 0.09 feet per log cycle at Q = 123 igpm. The drawdown at 10^4 minutes (from the graph) would be 1.925 feet. The drawdown at 10^7 minutes (20 years) would be 1.925 + (0.09 x 3) = 2.195 feet at a pumping rate of 123 igpm. Since the data have been adjusted to fully penetrating conditions, there is an available drawdown of 52 feet. Since the well yield equals Q/s x available drawdown, the 20-year safe yield becomes 123/2.195 x 52 = 2,900 igpm. This figure does not take into

account a larger component of well loss that would occur at higher rates of pumping, possible lower transmissibilites in untested parts of the formation, and the possible appearance of boundary effects at some later time. A progressive decrease in available drawdown with increased pumping and consequent lowering of transmissibility is also not considered. To take these factors into account a safety factor of 50% is rather arbitrarily applied and the final 20-year safe pumping rate becomes 1,450 igpm. Even this value should be applied with caution because the actual pumping rate used was so much lower than this figure.

The safe yield per well in the case of a well field will be considerably less than that calculated for a single well. This will vary with the well spacing used. However, in highly permeable materials such as the Grimshaw gravels, well spacing would have to be fairly great, due to a broad cone of influence.

Bail Tests and Short Pump Tests

Bail tests were carried out on most of the Research Council test holes that encountered water. They were conducted at a maximum rate of 20 imperial gallons per minute for a period of 2 hours, followed by a 2 hour period of recovery. One 2 hour pump test at 50 igpm was conducted. Toth (1966a, p. 72-76) discussed the bail test method and results in some detail. The general procedures described by Toth were applied in the Grimshaw area. The transmissibility of the formation was obtained by the use of the equation:

$$T = \frac{264Q}{s}$$

For the purpose of calculating the safe yield of the bailed well for a period of 20 years, this equation may be rearranged (Toth, 1966a) to:

$$Q_{s20} = \frac{TH}{2110}$$

where

Q_{s20} = safe yield supplied from existing storage for twenty years, and

H = total available drawdown, taken as the difference between the nonpumping level and the top of the aquifer, in the case of confined aquifers; and as the difference between the nonpumping level and the bottom of the well screen or slotted casing in the case of water-table aquifers.

The values of T and of Q_{s20} obtained from these formulae were:

1) for the Dunvegan sandstone T = 1,060 igpd/ft, Q_{s20} = 36 igpm (one test)

2) for 6 feet of intermediate level gravels T = 164 igpd/ft, Q_{s20} = 5 igpm (one test),

3) for wells completed in the Grimshaw gravels assuming drawdowns to the base of the screen or slotted casing, T varies from 58,500 to 897,000 igpd/ft and Q_{s20} varies from 277 igpm to 5,530 igpm.

Bail test results are shown in Table 5.

The bail test results are considered to be fairly reliable in the case of the confined aquifers becuase expected yields are low and the rate of bailing either approached or exceeded the calculated 20-year safe pumping rate. The values obtained, however, should be used with caution because the bailing period was too short to allow for the appearance of barrier boundaries which would adversely affect the results.

In the case of the Grimshaw gravels, extremely high values were obtained for both transmissibility and 20-year safe yield. These values cannot be accepted as representing the values that would be obtained with prolonged pumping at high rates. The rate of bailing was at much too low a rate for too short a period

Table 5. Bail test results, Grimshaw-Cardinal Lake area

Well	Location	Water-bearing formation	Setting of: (1) screen (2) slotted casing (3) aquifer in open-hole completion (depth in feet)	Depth & saturated thickness (m) of water-bearing formation (feet)	Available head (H) at start of test (feet)	Type of test	Duration of test (minutes)	Rate of discharge (Q) (igpm)	Drawdown (s) (unconverted for partial penetration (feet)	Specific capacity (igpm per foot of drawdown) = Q/s	Transmissibility (igpd/ft) $T = \frac{264Q}{s}$ (for well as completed)	Q_s20 (igpm) $Q_s20 = \frac{TH}{2110}$ (for well as completed)
RCA 65-1	SW4-13-83-25-W5	Dunvegan sandstone	(3) 134-152	134-152 (18 ft.)	72	Bail (bailing) Bail (recovery)	120 120	19	22	0.86	888 1,230 1,060*	30 42 36
RCA 65-6	NE8-13-84-25-W5	Intermediate level gravel	(3) 126-132	126-132 (6 ft.)	73	Bail (bailing) Bail (recovery)	120 120	5.3	32	0.165	- 164	- 5
RCA 65-1	SW4-13-83-25-W5	Grimshaw gravel	(2) 100-110	58-111 (53 ft.)	42	Bail (bailing) Bail (recovery)	120 120	20	0.67	30	52,800 53,000	1053*
RCA 65-2	NW5-29-83-23-W5	Grimshaw gravel	(2) 26- 36	13- 57 (44 ft.) "	13 13	Bail (bailing Bail (recovery) Pump (pumping) Pump (recovery)	120 120 120 120	20 51	0.065 0.70	308 73	352,000 277,900 - 897,600	2169 11712 - 5530
RCA 65-7	SW10-16-84-24-W5	Grimshaw gravel	(2) 34- 54		15	Bail (bailing) Bail (recovery)	120 120	20	0.11	182	- 220,000	- 1564
RCA 66-11	NE16-36-83-24-W5	Grimshaw gravel	(1) 51- 56 (prior to well development)	41- 93 (52 ft.)	10	Bail (bailing) Bail (recovery)	120 120	20	4.65	4.3	- 66,000	- 313
			(1) 51- 56 (after well development)	41- 93 (52 ft.)	10	Bail (bailing) Bail (recovery)	120 120	20	1.72	11.6	- 58,500	- 277

*Average

Figure 38
Saturated thickness of Grimshaw gravels, in feet

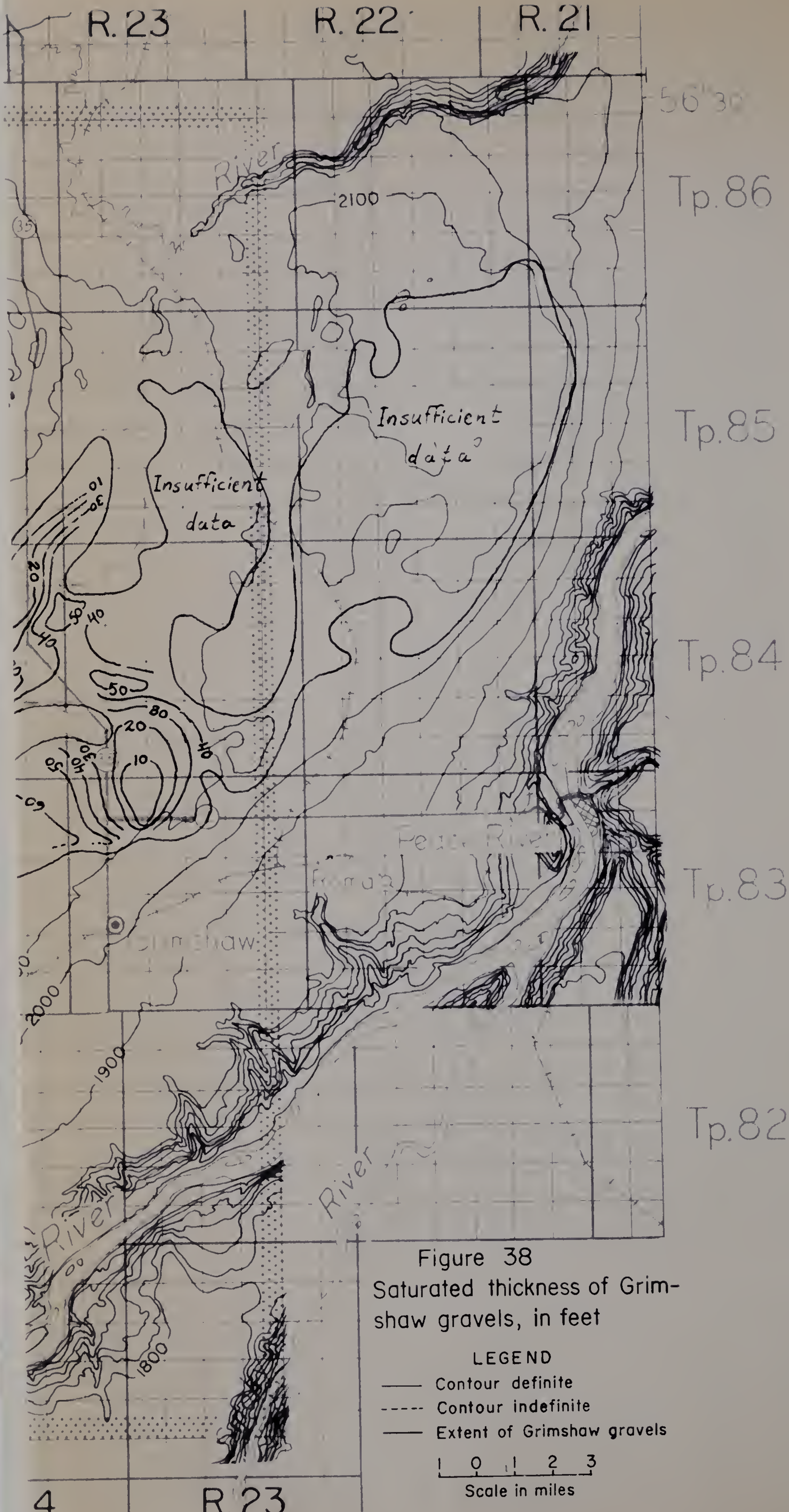


Figure 38
Saturated thickness of Grimshaw gravels, in feet

of time to properly evaluate such an aquifer, and as steady-state conditions were not attained, the results can be misleading. However, the tests do point out the high yield potential of these gravels over most or all of their extent. The values obtained are presented here only to illustrate the range of values that can be obtained under these conditions, and should not be taken to represent values that would be obtained at high rates of pumping for prolonged periods of time. Adjustment of the values to take effects of partial penetration into account could not be made because the partial penetration formulae assume steady-state conditions. Such conditions are not attained in the water-table case during a 2 hour test.

As determined from the 4-day pump test previously discussed, a 20-year safe pumping rate of somewhat over 1,000 igpm may be obtainable in areas of Grimshaw gravels removed from boundary conditions. However, lower pumping rates would be necessary near barrier boundaries. In the case of well fields, or closely spaced wells, interference between wells would necessitate lower rates of pumping.

Expected Yield from Aquifers in Grimshaw-Cardinal Lake Area

A groundwater probability map is included as enclosure 8. Values of transmissibility as determined from pump and bail tests and of apparent transmissibility (Farvolden, 1961, p. 10) as determined from reported production tests are shown on the map. A 20-year safe yield was calculated from the transmissibility value, and is also shown on the map.

Yields of over 100 igpm are possible over most of the area of the Grimshaw gravels and in alluvial terraces adjacent to the Peace River. Yields of 10 to 100 igpm may be expected from wells completed in sandstones of the Dunvegan Formation and in intermediate level sands and gravels. In uplands adjacent to the Peace River valley, in which the Dunvegan formation or intermediate level sands and gravels are not present at depth, yields of generally less than 10 igpm can be expected. In all cases a well depth of

500 feet or less is assumed.

Recoverable Groundwater in Grimshaw Gravels

The thickness of the water-saturated portion of the Grimshaw gravels can be obtained by superimposing the map of water-level contours (Encl. 7) on the map of bedrock topography (Encl. 5). This was done in the construction of figure 38. An average saturated thickness of about 30 feet is obtained, over the extent of the Grimshaw gravels. The gravels cover an areal extent of about 223 square miles or about 6.2×10^9 square feet. The total volume of water-saturated Grimshaw gravels is therefore about $30 \times 6.2 \times 10^9 = 1.9 \times 10^{11}$ cubic feet. If the average storage coefficient is assumed to be 0.25, then the total amount of water in storage is $1.9 \times 10^{11} \times 0.25 = 4.75 \times 10^{10}$ cubic feet. Assuming that 50% of this is recoverable, then recoverable reserves total about 2.4×10^{10} cubic feet.

If it is assumed that discharge out of the aquifer through springs and seepages and by evapotranspiration is balanced by recharge, then only withdrawal of water by man through pumping will tend to deplete the groundwater reserves. The present rate of withdrawal is probably less than 24 million cubic feet per year. However, assuming depletion will average this amount over the years, it would take only 100 years to deplete the reserves. This is possibly an overly pessimistic figure because as water levels dropped, spring and seepage flow would decrease and more water would be available for use. However, it points out the need for careful future observations of water-level trends, for determination of the groundwater budget, and for care in developing the precious resource that is available in this area. In addition, the fact that groundwater levels are so closely connected with the level of Cardinal Lake points to the need for preserving the lake. If the lake were drained (it has a maximum depth of just over 10 feet), water levels within the Grimshaw gravels would be expected to drop proportionately to the level to which the lake was lowered. Should the aquifer be extensively pumped at some future time, a source of recharge, in addition to infiltration of rainfall, might be provided by the damming of Cardinal Creek to raise the level of Cardinal Lake.

CONCLUSIONS AND RECOMMENDATIONS

A close relationship between geology, groundwater movement, and groundwater occurrence and quality has been demonstrated. The Grimshaw gravels form the principal aquifer within the map-area and cover some 223 square miles in areal extent. Intermediate level gravels and sands, sandstones of the Upper Cretaceous Dunvegan Formation, and surficial sands, gravels, and other materials are utilized in areas where the Grimshaw gravels are not present. The best quality waters occur within the Grimshaw gravels and in the area of the Whitemud Hills, and quality deteriorates with distance away from these areas. A considerable amount of water is lost out of the Grimshaw gravels annually through spring and seepage flow, and through flow into lower adjacent or nearby aquifers. A transmissibility of over 300,000 igpd/ft was obtained for the Grimshaw gravels from a 4-day pump test. A 20-year safe yield of over 1,000 igpm was calculated using this transmissibility value, plus the addition of a safety factor, but the actual safe yield could be less than this because of using too low a rate of pumping (123 igpm) to properly evaluate the aquifer, and because of partial penetration effects which are difficult to assess accurately.

A more precise evaluation of the potential yield to be expected from the Grimshaw gravels would require the construction of a properly developed well screened over the full saturated thickness of the gravels. A step-drawdown test should be conducted to determine the pumping rate necessary to test the aquifer adequately. This would presumably be at a rate of 1,000 igpm or more. Pumping at this rate with one or more observation wells should be carried on for at least 7 days to allow for the effects of delayed gravity drainage to dissipate.

Properly conducted short aquifer tests conducted by drillers on wells drilled for industry, municipalities, or individuals would be helpful in obtaining a better understanding of aquifer characteristics over a wide area. This type of testing is only too rarely done in Alberta. Lithologic logs should be made of all water wells drilled, and details of well construction and completion should be recorded. This type of information is now required by law in Alberta, but is not always obtained. The well owner, for his own protection, should insist that he be given this information. The author would also like to see samples taken of drill cuttings and turned in to some government agency for storage, cataloguing, and eventual examination. Drillers, and even geologists, are not infallible in their identification of types of rock or earth materials, particularly when identification is made by the naked eye.

A groundwater budget for the Grimshaw gravels has not been calculated because quantitative determinations of amounts of rainfall, runoff, infiltration, and evapotranspiration have not been made. Some instrumentation to determine these factors is desirable before increased development of this groundwater resource is undertaken. Records of the level of Cardinal Lake and of groundwater levels in selected wells in the Grimshaw gravels should also be kept. In this regard, a lake-level recorder and several water-level recorders in wells were installed in 1965 and are presently being maintained.

REFERENCES

Alberta Study Group (1954): Lower Cretaceous of the Peace River region; in Ralph Leslie Rutherford Memorial Volume, Western Canada Sedimentary Basin Symposium, Am. Assoc. Petroleum Geol., Tulsa, p. 268-278.

Allan, J. A. (1922): Geological reconnaissance in Alberta during 1921; in 2nd Ann. Rept., Sci. Ind. Res. Coun. Alberta Rept. 5, p. 34-42.

__________ (1928): Geological Survey Division; in 9th Ann. Rept.; Sci. Ind. Res. Coun. Alberta Rept. 22, p. 20-38.

Allan, J. A., and Carr, J. L. (1946): Geology and coal occurrences of Wapiti-Cutbank Area, Alberta; Res. Coun. Alberta Rept. 48, 43 pages.

Bostrom, R. C. (1967): Water expulsion and pingo formation in a region affected by subsidence; Jour. of Glaciology, Vol. 6, No. 46, p. 568-572.

Boulton, N. W. (1963): Analysis of data from nonequilibrium pumping tests allowing for delayed yield from storage; Proc. Institution Civ. Engrs., Vol. 26, No. 6693, p. 469-482.

Bryan, Kirk (1919): Classification of springs; Jour. Geol., Vol. 27, p. 522-561.

Burk, C. F. Jr. (1963): Structure, isopach, and facies maps of Upper Cretaceous marine succession, west-central Alberta and adjacent British Columbia; Geol. Surv. Can. Paper 62-31, 10 pages.

Butler, Stanley S. (1957): Engineering hydrology; Prentice-Hall Inc., 356 pages.

Cooper, H. H. Jr., and Jacob, C. E. (1946): A generalized graphical method for evaluating formation constants and summarizing well-field history; Trans. Am. Geophys. Union, Vol. 27.

Davis, S.N., and DeWeist, R.J.M. (1966): Hydrogeology; John Wiley & Sons, Inc., 463 pages.

Dawson, G.M. (1881): Report on an exploration from Port Simpson on the Pacific Coast, to Edmonton on the Saskatchewan, embracing a portion of the northern part of British Columbia and the Peace River country; Geol. Natl. Hist. Surv. Can. Rept. Prog. for 1879-1880, p. 1B-142B.

Dreimanis, A. (1962): Quantitative gasometric determination of calcite and dolomite by using Chittick apparatus; Jour. Sed. Petrology, Vol. 32, p. 520-529.

Farvolden, R.N. (1961): Groundwater resources Pembina area, Alberta; Res. Council Alberta Prelim. Rept. 61-4, 26 pages.

__________ (1963): Bedrock channels of southern Alberta; in Early contributions to the groundwater hydrology of Alberta; Res. Coun. Alberta Bull. 12, p. 63-75.

Flint, R.F. (1957): Glacial and Pleistocene geology; John Wiley and Sons, Inc., N.Y.

Folk, R.L. (1965): Petrology of sedimentary rocks; Hemphill's, Austin, Texas.

Freeze, R.A. (1966): Theoretical analysis of groundwater flow; Ph.D. thesis, University of California, Berkeley.

__________ and Witherspoon, P.A. (1966): Theoretical analysis of regional groundwater flow: 1. Analytical and numerical solutions to the mathematical model; Water Resources Research, Vol. 2, No. 4, p. 641-656.

Geiger, K.W. (1965): Bedrock topography of southwestern Alberta; Res. Coun. Alberta Prelim. Rept. 65-1, 14 pages.

Gleddie, J. (1954): Upper Cretaceous in western Peace River plains, Alberta; in Ralph Leslie Rutherford Memorial Volume, Western Canada Sedimentary Basin Symposium, Am. Assoc. Petroleum Geol., Tulsa, p. 486-509.

Gravenor, C. P. (1955): The origin and significance of prairie mounds; Amer. Jour. of Science, Vol. 253, p. 475-481.

Gravenor, C. P. and Bayrock, L. A. (1956): Stream-trench systems in east-central Alberta; Res. Coun. Alberta Prelim. Rept. 56-4, 11 pages.

Gravenor, C. P., Green, R., and Godfrey, J. D. (1960): Air photographs of Alberta; Res. Coun. Alberta Bull. 5, 38 pages.

Green, R., and Mellon, G. B. (1962): Geology of the Chinchaga River and Clear Hills (north half) map-areas, Alberta; Res. Coun. Alberta Prelim. Rept. 62-8, 18 pages.

Greer, J. E., and Christiansen, E. A. (1963): Geology and groundwater resources of the Wynyard area (72-P), Saskatchewan; Saskatchewan Res. Coun. Geology Div. Rept. No. 3, 56 pages.

Hem, John D. (1959): Study and interpretation of the chemical characteristics of natural water; U.S. Geol. Surv. Water-Supply Paper 1473, 269 pages.

Henderson, E. P. (1959): Surficial geology of Sturgeon Lake map-area, Alberta; Geol. Surv. Can. Mem. 303, 108 pages.

Holmes, C. D. (1947): Kames; Amer. Jour. Sci., Vol. 245, p. 240-249.

Hubbert, M. K. (1940): The theory of ground-water motion; Jour. Geol., Vol. 48(8), Part 1, p. 785-944.

Jacob, C. E. (1945): Partial penetration of pumping well, adjustments for; U.S. Geol. Surv. Water Resources Bull., August.

Jones, J. F. (1960): Groundwater geology, Beaverlodge district, Alberta; Res. Coun. Alberta Prelim. Rept. 59-2, 52 pages.

__________(1961): Surficial geology and related problems, Beaverlodge district, northwestern Alberta; M.Sc. thesis, Univ. of Western Ontario, 152 pages.

__________(1966): Geology and groundwater resources of the Peace River district, northwestern Alberta; Res. Coun. Alberta, Bull. 16, 143 pages.

Kozeny, J. (1933): Wasserkraft und wasserwirtschaft XXVIII.

Le Breton, E. Gordon (1966): Groundwater reconnaissance of the Lamont-Chipman area, Alberta; M.Sc. thesis, University of Wales, Swansea, Wales.

Leffingwell, Ernest de K. (1919): The Canning River region, northern Alaska; U.S. Geol. Surv. Prof. Paper 109, 243 pages.

MacKay, J. Ross (1962): Pingos of the Pleistocene Mackenzie delta area; Geographical Bulletin, No. 18, p. 21-63.

Mathews, W. H. (1963): Quaternary stratigraphy and geomorphology of the Fort St. John area, northeastern British Columbia; Dept. of Mines and Petroleum Resources, Victoria, British Columbia, 22 pages.

McLearn, F. H. (1918): Peace River section, Alberta; Geol. Surv. Can. Summ. Rept. 1917, Pt. C , p. 14-21c.

__________(1919): Cretaceous, Lower Smoky River, Alberta; Geol. Surv. Can. Summ. Rept.,1917, Pt. C, p. 1-7c.

______________(1926): New species from the Coloradoan of lower Smoky and lower Peace Rivers, Alberta; Geol. Surv. Can. Bull. 42, p. 117-126.

______________(1945): The Upper Cretaceous, Dunvegan Formation of northwestern Alberta and northeastern British Columbia; Geol. Surv. Can. Paper 45-27, 5 pages.

Meinzer, O. E. (1923): Outline of ground-water hydrology; U.S. Geol. Surv. Water-Supply Paper 494, 71 pages.

Meyboom, Peter; Van Everdingen, R.O., and Freeze, R. A. (1966): Patterns of groundwater flow in seven discharge areas in Saskatchewan and Manitoba; Geol. Survey of Canada, Bull. 147, 57 pages.

Müller, Fritz (1959): Observations on pingos; Meddelelser om Grønland, Vol. 153, No. 3, 1959, 127 pages; in National Research Council of Canada, Tech. Translation 1073, translated by D. A. Sinclair, Ottawa, 1963.

Muskat, Morris (1937): The flow of homogeneous fluids through porous media; McGraw-Hill Book Co. Inc., New York.

Pissart, A. (1963): Les traces de "pingos" du Pays de Galles (Grande-Bretagne) et du Plateau des Hautes Fagnes (Belgique); Zeitschrift fur Geomorphologie, 7, p. 147-165.

Porsild, A. E. (1938): Earth mounds in unglaciated arctic northwestern America; Geog. Review, Vol. 28, p. 46-58.

Prickett, T. A. (1965): Type-curve solution to aquifer tests under water-table conditions; Ground Water, Vol. 3, No. 3.

Reeder, S. W., and Odynsky, Wm. (1965): Reconnaissance soil survey of the Cherry Point and Hines Creek area; Univ. of Alberta Bull. SS-6; Res. Coun. Alberta Rept. 85, 102 pages.

Rutherford, R. L. (1930): Geology and water resources in parts of Peace River and Grande Prairie districts, Alberta; Sci. Ind. Res. Coun. Alberta Rept. 21, 80 pages.

_______________ (1937): Saskatchewan gravels and sands in central Alberta; Trans. Roy. Soc. Can., Vol. 31, Sec. 4, p. 81-95.

Seaber, Paul R. (1965): Variations in chemical character of water in the Englishtown formation, New Jersey; U.S. Geol. Surv. Prof. Paper 498-B.

Stelck, C. R. (1962): Upper Cretaceous, Peace River area, British Columbia; Edmonton Geol. Soc. Fourth Ann. Guide Book, p. 10-21.

Stelck, C. R. and Wall, J. H. (1954): Kaskapau foraminifera from Peace River area of western Canada; Res. Coun. Alberta Rept. 68, 38 pages.

___________________________ (1955): Foraminifera of the Cenomanian Dunveganoceras zone from Peace River area of western Canada; Res. Coun. Alberta Rept. 70, p. 1-28.

Stelck, C. R., Wall, J. H., and Wetter, R. E. (1958): Lower Cenomanian foraminifera from Peace River area, western Canada; Res. Coun. Alberta Bull. 2, Pt. 1, p. 1-35.

Taylor, R. S. (1958): Some Pleistocene lakes of northern Alberta and adjacent areas; Edmonton Geol. Soc. Quart., Vol. 2, No. 4, p. 1-9.

____________ (1960): Some Pleistocene lakes of northern Alberta and adjacent areas (revised); Jour. of the Alberta Soc. of Petroleum Geologists, Vol. 8, No. 6, p. 167-178.

Theis, C. V. (1935): The relation between the lowering of piezometric surface and the rate and duration of discharge of a well using ground-water storage; Trans. Am. Geophys. Union, 16th Ann. Meeting, Pt. 2.

Toth, J. (1962): A theory of groundwater motion in small drainage basins in central Alberta, Canada; Jour. of Geophys. Research, Vol. 67, No. 11, p. 4375-4387.

_______ (1963): A theoretical analysis of groundwater flow in small drainage basins; Jour. Geophys. Research, vol. 68, No. 16, p. 4795-4812.

_______ (1966a): Groundwater geology, movement, chemistry, and resources near Olds, Alberta; Res. Coun. Alberta Bull. 17, 126 pages.

_______ (1966b): Mapping and interpretation of field phenomena for groundwater reconnaissance in a prairie environment, Alberta, Canada; Bull. Intl. Assoc. Sci. Hydrol., XI^{e} Année, No. 2, p. 1-49.

Wall, J. H. (1960): Upper Cretaceous foraminifera from the Smoky River area, Alberta; Res. Coun. Alberta Bull. 6, 43 pages.

Walton, William C. (1962): Selected analytical methods for well and aquifer evaluation; Illinois State Water Survey Bull. 49, 81 pages.

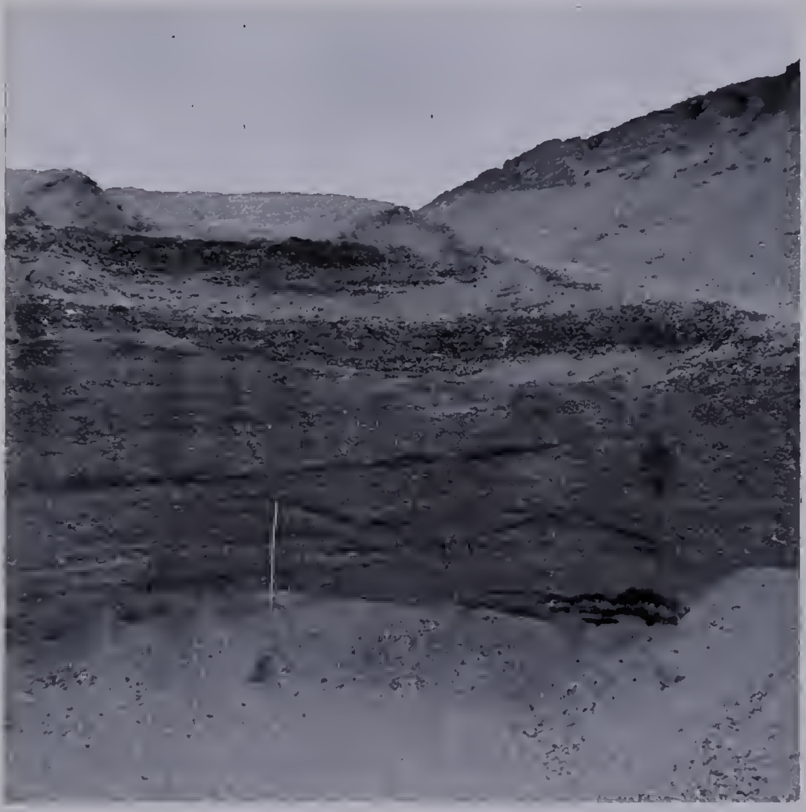
Warren, P. S. (1939): The Flaxville plain in Alberta; Trans. Roy. Can. Inst. Vol. 22, p. 341-349.

Wentworth, C. K. (1922): A scale of grade and class terms for clastic sediments; Jour. of Geology, Vol. 30, p. 377-392.

Wickenden, R. T. D. (1951): Some Lower Cretaceous sections on Peace River below the mouth of Smoky River, Alberta; Geol. Surv. Can. Paper 51-16, 47 pages.

Wyatt, F. A. (1935): Preliminary soil survey of the Peace River-High Prairie-Sturgeon Lake area; Res. Coun. Alberta Rept. 31, 28 pages.

IA - Outcrop section at locality 66-102
Northeast $\frac{1}{4}$, sec. 29, twp. 83, rge. 21 W5th Meridian
(see fig. 11 for schematic log of section)



IB - Gravel pit in " Grimshaw gravels "
Southeast $\frac{1}{4}$, sec. 36, twp. 81, rge. 1 W6th Meridian

PLATE I

Raised beach ridges (sand & gravel) accentuated by vegetation contrast.
Note slight rise in topography.
Southeast $\frac{1}{4}$, sec. 15, twp. 82, rge. 26 W5th Meridian

PLATE II

IIIA - Beach ridge 500 feet from shore of
Cardinal Lake, Lac Cardinal Provincial Park

IIIB - Well developed " varves "
Northeast $\frac{1}{4}$, sec. 11, twp. 82, rge. 26 W5th Meridian

PLATE III

Well marked strandlines south of Berwyn.
Note slumping in lower right hand corner typical
of valleys developed in areas of thick drift cover.
Gov't of Alberta air photo $\frac{160 - 5602}{1572 \quad 239}$

Scale 1" = 3333'

PLATE IV

Flutings in eroded till plain forming
southern arm of glacial Lake Cardinal.
Gov't of Alberta air photo $\frac{160\ 5603}{1573\ \ 43}$

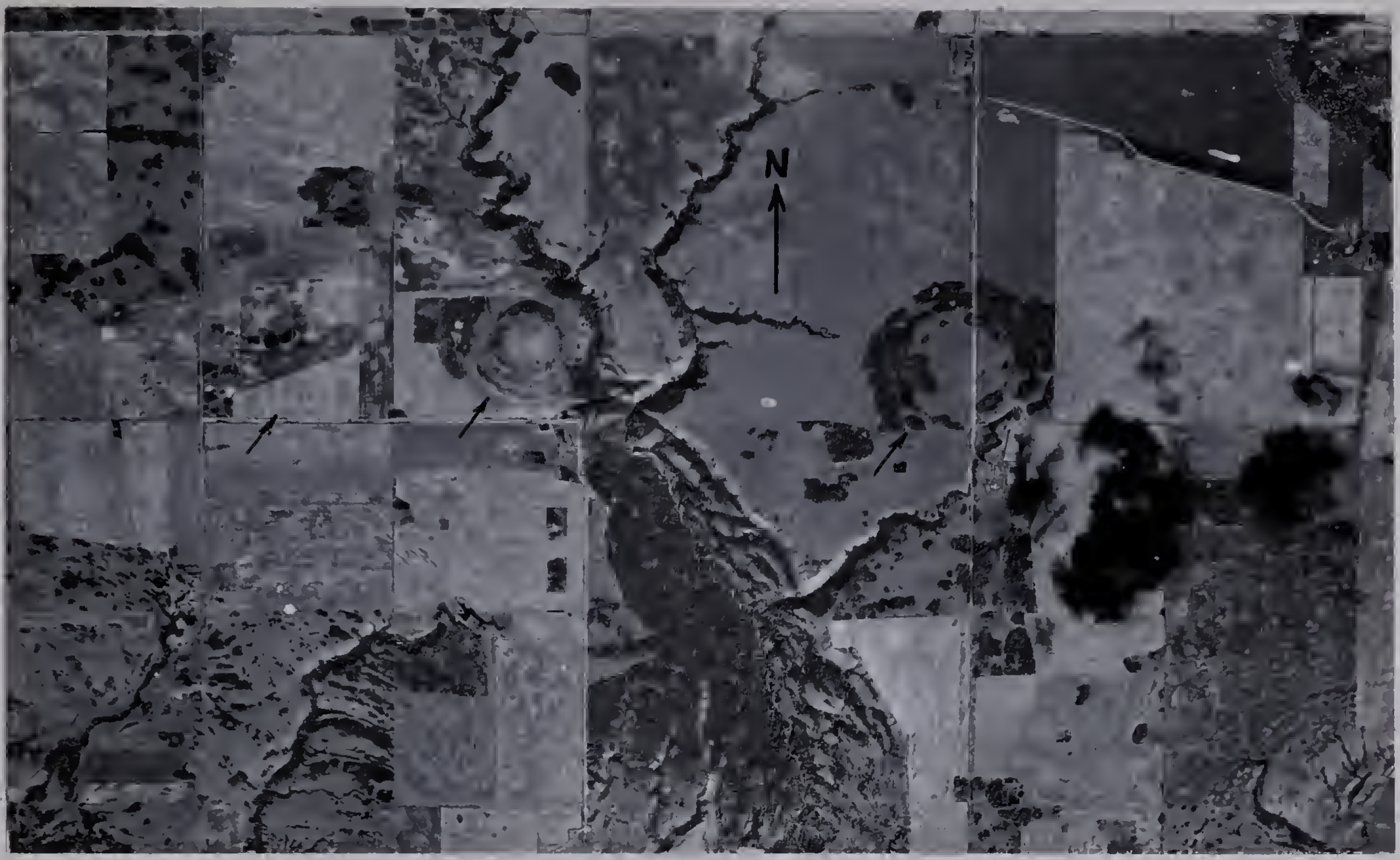
Scale 1" = 3333'

PLATE V

A) Earth mound in lsd. 12, sec. 14,
twp. 82, rge. 24 W5th Meridian.
-ground view

B) Earth mound-aerial view,
same location as above.
Gov't of Alta. air photo
162A-5605 - approx. scale 4"=1 mile
2346-52-64

PLATE VI



A) Earth mounds south of Fairview
sections 21 & 22, twp. 80, rge. 3W6th Mer.
Gov't of Alta. air photo $\frac{160\text{-}5516}{1571\text{-}434}$ - Approx scale 1"=3333'

B) Spring of stream-bank sub-type.
SW $\frac{1}{4}$, sec. 29, twp. 82, rge. 23 W5th Mer.
Note dirt fan built out from spring,
and phreatophytic vegetation.

PLATE VII

VIIIA - Hillside exposure of lacustrine silt and clay overlying till. Locality 65-139.
Southwest $\frac{1}{4}$, sec. 4, twp. 82, rge. 24 W5th Mer.
Photo taken from above spring at silt-till contact.

VIIIB - Locality 65-207
Northeast $\frac{1}{4}$, sec. 34, twp. 83, rge. 21 W5th Mer.
Seepages (dark areas) from sand and gravel lenses within till. Willows grow at point just below photo.

PLATE VIII

Appendix I. Lithologic descriptions of outcrop sections, Grimshaw-Cardinal Lake area

All sections were measured from the base upwards with 5-foot staff. Elevations were estimated from topographic maps. Descriptions are from field notes.

Locality 65-60

SW 1/4, Lsd. 15, Sec. 20, Tp. 82, R. 23, W. 5th Mer.

Started measuring in heavy bush above creek.

Cumulative thickness (feet)	Description
	Top of creek bank. Elevation about 1,800 feet. Hummocky topography (3 to 6 feet of relief).
115-125	Silt, resistant, yellowish brown, finely laminated to massive (see Appendices III and IV)
110-115	Silt; 12 inches of dark grey clay at top
75-110	Clay, dark grey, laminated in places; soft, but baked hard on surface; 50% silt laminations in lower 5 feet; 95% clay 80-110 feet (see Appendices III and IV)
73- 75	Silt lens, varies from 4 inches to 2 feet thick; thin streak of clay (1/2 inch)
65- 73	Till, yellowish brown weathering; forms a cliff
60- 65	Till, 2 feet of clean medium sand near base; probably in place
40- 60	Slump; mixed silt and till
0- 40	Covered with slumped material, mainly clay, from above

Locality 65-61

Lsd. 14, Sec. 20, Tp. 82, R. 23, W. 5th Mer.

Started measuring from creek level at about 1,700 feet elevation

Cumulative thickness (feet)	Description
40	Slump, mainly till
30- 40	Interlensing sand and till
10- 30	Mainly sand, fine to medium grained, clean, well sorted; some fine sand and silt, some pebbly sand (see Appendix III); a few thin clay beds
0- 10	Covered, with slump, brush

Locality 65-77

Lsd. 5, Sec. 18, Tp. 83, R. 22, W. 6th Mer.

Measuring from creek level upwards

162-165	Soil profile to top of creek bank at about 1,850 feet elevation
150-162	Clay, dark grey, a few lenses of lighter colored silt
105-150	Largely slumped. Yellowish brown silt to very fine sand on surface. Poor exposure in upper 10 feet of very fine sand and silt interlaminated with dark brown clay. Some alkali near top of unit.
104-105	Sand, fine to medium grained, clean. Sand lies on definite till.
30-104	Slump-covered. Mainly till with patches of sand.
0- 30	Heavily tree-covered.

Locality 65-98

Lsd. 4, Sec. 33, Tp. 82, R. 23, W. 5th Mer.

Very poorly exposed section on creek bank with heavy cover of bunch grass. Heavy tree growth in lower part. Started measuring from about half way up bank.

	Top of creek bank at about 1,830 feet elevation. Hummocky topography with 6 to 8 feet of relief, locally 10 to 12 feet.
38- 60	Covered, no stones on surface, probably silt and clay as below.
20- 38	Poorly exposed; interlaminated silt and clay
0- 20	Covered, stony on surface, probably till. Forms a shoulder.

Locality 65-99

Lsd. 4, Sec. 2, Tp. 83, R. 23, W. 5th Mer.

Section along road crossing creek.

Cumulative thickness (feet)	Description
30- 45	Clay, dark grey, poorly exposed. A few lenses of silt to 3 inches thick. Some gypsum crystals along fractures in lower part of unit. Top of creek bank at about 1,830 feet elevation.
10- 30	Silt, very finely laminated, finely cross bedded in places, but mostly horizontally laminated; finer grained upwards; bands of dark grey clay increase in number upwards to about 40% at top. A few stones in one zone near top. Some alkali in lower part.
0- 10	No exposures; tree cover

Locality 65-121

Lsd. 4, Sec. 13, Tp. 81, R. 26, W. 5th Mer.

Section along road across creek.

	Top of creek bank at about 1,890 feet elevation. General topography is hummocky with about 4 feet of relief.
17- 25	Clay, dark grey, poorly exposed. Thickness ranges from 5 to 8 feet.
0- 17	Till

Locality 65-122

Lsd. 12, Sec. 8, Tp. 80, R. 1, W. 6th Mer.

Section on north side of Peace River valley. Started measuring in Dunvegan Formation on valley side. There are more bedrock exposures farther downslope. Whitish efflorescence (alkali?) in places on exposed surface of Dunvegan Formation. "Ironstone" in the descriptions below refers to resistant rusty weathering, dark grey, very fine grained or finely crystalline calcareous or dolomitic clay material.

Cumulative thickness (feet)	Description
237-292	Covered; grass and trees. Shoulder at 277 feet. Top of river bank at about 1,880 feet elevation.
230-237	Silt, massive to laminated. Contains a 1-foot bed of till and a 1-foot bed of dark grey soft clay. Poorly exposed.
225-230	Covered.
217-225	Silt with thin laminations of dark grey, fissile clay 15-20%.
214-217	Till; lenses of silt 10-50%. Varies to 6 feet thick (see Appendix III)
204-214	Clay, dark grey, good fissility, abundant stones in first 18 inches probably derived from underlying gravels. A few scattered small stones in remainder of unit, some of which are Shield-type igneous and metamorphic pebbles (see Appendix III).
160-204	Gravel, fine to cobble sized, sand only as matrix material; gravel is mainly well rounded quartzites, also pebbles of chert, some volcanic rocks, igneous rocks, and low-grade metamorphics, dark sandstones and conglomerates. Lower 4-5 feet has a heterogeneous poorly-sorted mixture of subangular pebbles, cobbles, and boulders of ironstone, sandstone and siltstone (Dunvegan Formation type), cone-in-cone calcareous shale containing marine fossils. Imbrication of pebbles and cobbles in lower 2 feet at slight angle. Gravel is dry throughout.
52-160	Shale (Kaskapau Formation) dark grey, soft, fissile, chippy. (Small discontinuous gravel terraces of the Peace River at 90 and 120 feet. The gravels are 6 to 8 feet thick.) Top of bedrock.
49 1/2-52	Chumed sandstone, with clay as above; ironstone blebs in upper part; 6-8 inches continuous band of hard ironstone at base; discontinuous 4-6 inches band of ironstone concretions at top. Unit is resistant because of ironstone. Very rusty in upper one foot.(Upper unit of Dunvegan Formation.)
47-49 1/2	Sandstone, as below, but recessive, very loosely unconsolidated; upper 6-8 inches appears churned by organisms (dark grey clay intermixed with the sandstone).
37- 47	Sandstone, cliff-forming, friable but more resistant and better cemented than lower sandstone, weathers light yellowish brown.
13- 37	Recessive interval, largely covered, soft very sandy clay shale at base grading to soft dark grey clay shale at top. Bands of ironstone and sandy ironstone to 1-foot thick with wide lateral continuity. Three such bands, 1 inch thick, 3 inches apart in middle of unit. Thin (<2") platy ironstone bands in lower and upper parts of unit.

Cumulative thickness (feet)	Description
0- 13	Sandstone, soft, friable, fine grained, salt and pepper appearance, weathering light yellowish brown, cliff-forming; in beds 6 inches to 3 feet thick separated by thin (1/4" to 1") streaks of sandstone containing ironstone that etches out on surface. Sandstone is fine horizontally laminated; one 6-12 inch bed is cross-laminated at about 25°. Local seepages from base of unit.

Locality 65-125

Lsd. 9, Sec. 9, Tp. 82, R. 24, W. 5th Mer.

Excellent roadside exposure of lacustrine laminated (varved?) clay and silt.

21 1/2-23 1/2	Soil profile. Top of section at about 1,880 feet elevation.
18-21 1/2	Silt, finely laminated with grey clay; 13 sets of laminae. Individual silt bands range from horizontally laminated to cross-laminated, and ripple marked; a 1" band of fine to medium grained sand near base.
12- 18	Mainly clay, brownish grey to grey, mostly blocky; thin silt laminations in upper 18 inches. Apparently non-laminated in lower 4 1/2 feet. Upper 18 inches of unit contains 62 sets of laminations or varves. Some of the bands show brecciated internal structure.
10- 12	Rather poorly exposed. Varved silt and clay (55-45 ratio). Varve couplets appear to average about 1 1/4 inches in thickness, ranging from 1/2 inch to 2 inches, but difficult to tell for sure.
6- 10	Varved silt and clay (60-40 ratio); 7 pairs of varves ranging from 3 inches to 8 inches in thickness per set. Silt is light yellowish brown, clay is brownish grey.
0- 6	Silt, light yellowish brown; contains six 2 inch bands of continuous or brokenly continuous brownish grey clay which may represent winter clay deposition. The summer silt layers range from 2 inches to 1 1/2 feet. The thicker silt layers contain abundant blebs and contorted lenses of brownish grey clay, about 10%.

Locality 65-139 (Plate VIIIA)

Lsd. 9, Sec. 4, Tp. 82, R. 24, W. 5th Mer.

Poorly exposed section on creek bank. Start measuring from about half-way up creek bank.

Cumulative thickness (feet)	Description
66- 68	Soil profile. Top of creek bank at about 1,850 feet elevation.
62- 58	Silt, poorly exposed; with clay interbedded.
58- 62	Clay, dark grey
55- 58	Silt, yellowish brown. Poorly exposed; with interbedded clay.
15-55	Silt, light yellowish brown (see Appendix III).
10- 15	Covered. Probably silt as above.
0- 10	Covered, stones on surface, probably till. Forms a shoulder.

Locality 65-140

Lsd. 8, Sec. 5, Tp. 82, R. 24, W. 5th Mer.

Ditch cut along road. Not well exposed.

29- 31	Soil profile. Top of ditch bank at about 1,850 feet elevation.
27- 29	Clay and silt
22- 27	Clay, dark grey weathering
14- 22	Clay, soft, brownish grey weathering.
4- 14	Interlaminated clay and silt (65-35 ratio). Exposure too poor to enable counting of laminae.
0- 4	Silt, light yellowish brown, finely horizontally laminated to cross-laminated.

Locality 65-143

Lsd. 3, Sec. 6, Tp. 82, R. 24, W. 5th Mer.

A good ditch cut exposure.

14- 17	Soil profile. Top of ditch cut at about 1,880 feet elevation.
10 1/2-14	Interlaminated clay and silt; varves average 1 inch per set or slightly less in lower 1 foot; individual varves not distinguishable in remainder of unit.
9-10 1/2	Silt and grey clay (60-40 ratio), coarsely varved, 1-2 inch per set of varves; some pebbles; pods of silt disrupt varving.
5-9	Silt and interlayered brownish clay, 30%. Clay is locally pebbly.

Cumulative thickness (feet)	Description
0- 5	Till, alkali crust on surface in places.

In ditch cut across the road, silt is dominant 60-80%, and original varving largely destroyed; pebbles fairly abundant, and a few ice-rafted boulders to 12 inches in diameter are present.

Locality 65-206

Lsd. 2, Sec. 13, Tp. 84, R. 22, W. 5th Mer.

Creek-cut section. Badly slumped in lower parts. Started measuring near top of valley side.

33- 73	Grass-covered to top of creek bank at about 1,700 feet elevation.
27- 33	Interlaminated clay and silt. May be slumped.
13- 27	Sandy to silty till-like mass. Possibly represents mud-slide into lake.
10- 13	Sand, fine grained, fairly clean; lenticular, ranges from 1 to 3 feet thick; some gravel intermixed.
0- 10	Till, dark grey, weathers greyish to brownish, irregularly fractured (see Appendix III).

Locality 65-207 (Plate VIIIB)

Lsd. 15, Sec. 34, Tp. 83, R. 21, W. 5th Mer.

Creek bank section. Creek at about 1,470 feet elevation. Measuring from creek level upwards.

235-250	Covered to top of creek bank at about 1,720 feet elevation. Probably silt as below. Hummocky topography; hummocks are mainly silt.
200-235	Silt, massive, cliff-forming; interbeds of grey clay about 15%.
188-200	Clay, medium grey, platy to blocky, unctuous, lacks silt laminations (see Appendix III).
177-188	Till, massive, cliff-forming; more stony and silty than the lower till (see Appendix III), and does not exhibit vertical jointing. A few horizontal shear planes and indistinct horizontal jointing(?) are present.
165-177	Mixed till, sand and gravel in about a 60-40 ratio.

Cumulative thickness (feet)	Description
158-165	Mainly sand, some gravel; water-saturated in lower 2-3 feet; sand is fine to medium grained, locally cross-laminated where water-saturated; the upper 2 feet of the unit is dry, clean, medium to coarse grained sand ranging to granule size. The interval from 160-163 feet is intermixed till, gravel, and sand.
35-158	Till, continuously exposed but may be slumped in lower parts, massive, dark brownish grey; till is clayey and pebbles are small; vertically jointed and somewhat cliff-forming (see mechanical analysis conducted on sample from the interval 148-158 feet - Appendix III).
0- 35	Slumped. Till.

Locality 65-243

Secs. 21 & 22, Tp. 82, R. 23, W. 5th Mer.

Poorly exposed section pieced together from small exposures along road leading down to the Peace River.

	Top of bank at about 1,800 feet elevation.
365-380	Silt, pale yellowish brown.
345-365	Clay, dark brownish grey, soft, flaky, minor silt and dark grey clay.
340-345	Till, dark brownish grey, poorly exposed.
50-340	Poorly exposed interval. The few exposures of till, silt, and clay are probably slumped.
40- 50	Till, probably slumped.
25- 40	Sand, ranges from fine to coarse grained.
20- 25	Covered.
0- 20	Clay or soft shale, medium grey, platy, locally laminated; a few lenses of soft, finely cross-bedded yellowish silt up to 1-foot thick about 15%. Shaftesbury Formation(?).

Locality 65-244

Secs. 27, 28, 32, 33, Tp. 81, R. 24, W. 5th Mer.

A very poorly exposed section pieced together from small exposures along road leading down to the Peace River. Much slumping has occurred and very little material is in place. Because of the nature of the exposures, this section is described in a different manner than the others.

Approximate elevation in feet above sea level	Description of exposure
1800	Top of bank, laminated silt.
1500	Uppermost till exposure, may be slumped. Scattered exposures of silt above till are probably slumped.
1500-1180	Scattered exposures of silt and till. Probably all slumped. Small pockets of gravel mixed with till at 1320 feet.
1180	A few feet of sand mixed with till and silt. Probably largely or entirely slumped material.
1150	Top of terrace to Peace River.

Locality 65-245

Secs. 11 & 14, Tp. 81, R. 25, W. 5th Mer.

Poor exposures along a road leading down to the Peace River. Started measuring at about 1,350 feet elevation from back edge of terrace to Peace River.

Cumulative thickness (feet)	Description
	Top of section. The materials from 68-156 feet are almost continuously exposed in a series of hummocks along the road, but may be slumped.
153-156	Clay and silt with streaks of sand and gravel.
148-153	Sand, with lenses of silt and of gravel.
140-148	Varved clay and silt. Slumped(?)
135-140	Till(?) 40% mixed with coarse gravelly sand.
85-135	Slumped, mainly till and clay.
68- 85	Probably slumped. Till, silt, clay and sand.
63- 68	Clay, gritty, till-like, poorly bedded to platy. Shield-type igneous pebbles are present.
60- 63	Sand, fine to very fine grained, micaceous, dark grey in color due to abundance of black chert grains.
52- 60	Gravel, no Shield-type pebbles noticed, predominantly well rounded quartzite pebbles; locally derived ironstone and soft platy sandstones also present; Cordilleran rock types, ie. volcanics, igneous rocks, low grade metamorphics, dark sandstones and conglomerates, scarce but present.
30- 52	Continuous exposures beneath slumps of till of: sand, brownish, well sorted, medium-coarse grained, with abundant mica flakes and black chert.
0- 30	Covered.

Locality 66-101

SE 1/4, Lsd. 7, Sec. 29, Tp. 83, R. 21, W. 5th Mer.

Section on Heart River, started measuring at tiver level

Cumulative thickness (feet)	Description
281-366	Covered to top of ridge. Elevation of top of ridge about 1,435 feet above sea level.
226-281	Interbedded silt (to very fine sand) 80%, and clay. About 80% covered; probably more clay in covered portions. Clay is dark grey in bands from a fraction of an inch to 1/2 inch thick, a few thicker bands up to 12 inches thick.
218-226	Sand, as below but more reddish and cleaner.
190-218	Sand, fine to medium grained, massive, well horizontally bedded; carbonaceous and mica flake layers as partings in lower 20 feet. Partings more closely spaced in upper 8 feet to give banded appearance. Locally, lenses of gravel with abundant Shield-type pebbles. Lowest and largest lens is 5 feet above base of unit and measures 3 feet x 30 feet.
174-190	Gravel, pea size; lower 5 feet is incline bedded to south at about 20°. Upper 11 feet horizontally bedded to incline bedded to south 5° to 10°. Shield-type igneous pebbles in this unit.
171-174	Covered.
167-171	Sand, fine to medium grained.
157-167	Gravel, with lenticular interbeds of medium to coarse grained sand 2-6 inches (20%).
154 1/2-157	Sand, very fine grained, to silt; ripple bedded, carbonaceous laminations.
145-154 1/2	Gravel, mostly fine pea gravel, very little sand in matrix; fairly well bedded, individual beds are very well sorted.
133-145	Gravel, massive, less sand in matrix than in unit below.
113-133	Gravel, sandy; some sand lenses; well horizontally bedded.
109-113	Sand, gravelly
69-109	Covered with scree and brush. Steep slope.
54 1/2-69	Covered to top of first "bench" which probably represents a postglacial terrace, 5 feet of gravel exposed at top of interval and 1-foot of gravel at bottom.
54-54 1/2	Sandstone, coarse grained, dark grey, quartzitic, hard. Top of exposed bedrock (top of PeaceRiver formation.)
53-54	Shale, dark grey, very wet, broken.

Cumulative thickness (feet)	Description
30- 53	Sandstone, massive, fine grained, some carbonaceous streaks.
28- 30	Sandstone, fine grained, carbonaceous with 2-3 inches of coal at base, followed by 4-6 inches of dark wet sandstone, 8 inches of light colored sandstone and then carbonaceous sandstone to top of unit; recessive interval.
8- 28	Sandstone, fine grained, carbonaceous, massive in upper 13 feet but with some carbonaceous partings. Lower 7 feet is banded with carbonaceous partings and slightly more recessive.
0- 8	Sandstone, massive, resistant; one foot zone of ironstone nodules at top, and a few nodules in lower 2 feet. Slightly downstream 4 feet of platy more recessive sandstone is exposed beneath this unit.
	Base of section at river level at about 1,070 feet elevation.

Locality 66-102

S 1/2, Lsd. 9, Sec. 29, Tp. 83, R. 21, W. 5th Mer.

Section on Heart River, downstream and cross-river from 66-101. Grass-grown rolling hills extend to the top of the valley wall from the top of the exposed section. Upper part of section later covered during road construction along the valley wall.

218-233	Clay, non-silty, platy, very smooth, soapy feeling (unctuous), light brownish grey. Exposed in slump cut; otherwise hillside is grass-grown or has jumble of clayey material containing rocks which resemble till but are actually slump and slide debris.
209-218	Clay, as above, but in small flat chips rather than platy.
189-209	Silt and clay, interbedded, contains ice-rafted pebbles, lower 10 feet very poorly exposed.
179-189	Covered; grass-grown.
156-179	Silt and very fine grained sand, interlayered, lenses of gravel with angular Shield-type pebbles; largely covered, not indurated as in resistant unit below, more recessive than that unit
144-156	Silt to very fine grained sand, massive; upper unit of resistant, cliff-forming interval.
135-144	Silt and very fine grained sand, interbedded, hard; middle unit of cliff-forming interval; clayey interbeds <5%; gravel or gravelly lenses common (10-30% of unit) the thickest being 3 feet thick and occurring at the base of the unit at west end of exposure; gravel is very angular, very poorly sorted, and predominantly of Shield-type pebbles.

Cumulative thickness (feet)	Description
115-135	Silt and very fine sand, well laminated to thinly bedded; basal unit of cliff-forming interval; in lower 5 feet some fairly continuous pebbly sand or very fine gravel layers to 1 1/2 feet thick; pebbles and gravel as in unit above; a few (about 8%) clay interbeds to 3 inches thick, medium grey; discontinuous stringers of black burnt wood(?) in one of these clay interbeds.
113-115	Clay, massive, unbedded, yellowish grey; contains squashed and comminuted shells of gastropods and ostracods, most abundant in upper few inches of unit.
110-113	Silt, yellowish, interlaminated with very fine to fine grained sand, minor clayey partings.
100-110	Covered interval.
92-100	Gravel, sandy, mainly fine pea size, some boulders; largely covered by slumping from above; some Shield-type igneous pebbles present which appear to be in place.
74- 92	Shale, soft, dark grey, papery; prominent yellowish efflorescence on weathered surface; light grey weathering appearance from a distance; top of bedrock (Shaftesbury Formation).
64- 74	Sandstone, fine grained, massive, some continuous dark bands of carbonaceous and micaceous material as below but thinner and less abundant (5 to 6%) (top of Peace River Formation). Abrupt, sharp contact with overlying shale.
52- 64	Sandstone, fine grained, prominently layered (10-12%) with dark carbonaceous and micaceous bands to 2 inches thick.
49- 52	Mudstone, soft, dark grey, interlaminated with silty mudstone, pale yellowish brown which varies to silt or very fine sandstone; recessive unit.
48- 49	Sandstone, fine grained, resistant.
47- 48	Sandstone, soft, carbonaceous, 2 inches of soft black shale at top; recessive unit; correlative with coally zone at 28-30 feet of section at locality 66-101.
32- 47	Sandstone, fine grained, massive but with some continuous carbonaceous bands (5%) to 2 inches thick.
26- 32	Sandstone, fine grained, banded with carbonaceous and micaceous interbeds to 2 inches thick.
6- 26	Sandstone, fine grained, massive.
0- 6	Sandstone, fine grained; notched by river erosion, prominently mottled on surface with whitish alkali salts mainly along horizontal and sub-vertical joints. Higher in the section alkali is absent except along some prominent near-vertical joints which also show rust staining. Sandstone is damp in lower 3 to 4 feet above the river, probably due to capillary retention of water from the river. River level estimated at 1,060 feet elevation.

Appendix II. Lithologic descriptions of test holes

Some of the following descriptions were made from examination of drill cuttings under the binocular microscope, together with pertinent observations from notes made at the drill site. Sample color was determined by use of the Munsell soil color chart (1954 edition) on dry samples. Where Munsell color designations do not appear, samples were described at the well site from examination by hand lens, unless otherwise indicated.

Elevations were estimated from topographic maps, except for some of the Research Council test holes which were levelled in, in some cases. In other cases, elevation was determined by aneroid barometer. Unless otherwise indicated, the elevations were estimated.

RCA 65-1

SW 1/4, Lsd. 4, Sec. 13, Tp. 83, R. 25, W. 5th Mer.
Elevation: 2,173 feet (levelled) Kerndale Hall

Cumulative depth (ft.)	Description
2- 4	Silt, 5Y 6/3, pale olive, non-calcareous, micaceous (muscovite), extremely fine (powdery) (wet color 2.5 Y 4/2, dark greyish brown)
4- 14	Silt, 2.5Y 5/2, greyish brown (wet color 2.5Y 3/2, very dark greyish brown), as above. Streaks or bands of 5YR 4/4 (dry), reddish brown silt as above, about 10% of sample
14- 19	Silt, sandy, visually grain sizes about 60% silt, 40% sand, ranging from 0.04 to 0.08 mm, very rare grains to 0.1 or 0.2 mm. Grains angular, about 90% light colored, 10% black, rare yellowish and reddish grains. Over-all color (dry) 5Y 6/3, pale olive.
19- 20	Silt as at 2-14 ft.
20- 26	Till, matrix is extremely fine (powdery) silt, micaceous, over-all color 5Y 6/3 (dry), pale olive
26- 40	Gravel, very little sand
40- 70	Gravel, sandy
70- 75	Sand, fairly well sorted, subangular to subrounded; about 15% black chert, micaceous. Grain size 0.2 to 0.8 mm. Many larger grains. Average about 0.4 mm. Over-all color 5Y 6/4, pale olive.

Cumulative depth (feet)	Description
75- 85	Sand, over-all color 5YR 4/4, reddish brown; approximately same grain size (to slightly coarser) and composition as before; more gravelly.
85- 90	Sand as at 70-75 ft., but slightly coarser and slightly more yellowish but still 5Y 6/4, pale olive
90- 95	Gravel, sandy
95-100	Sand, very coarse, 1-2 mm, mostly subrounded to rounded, well sorted, about 25% black chert, 25% vein quartz; remainder predominantly vari-colored quartzites from whitish to dark brown (about 45%); other rock types about 5% including some volcanics. Over-all color is salt and pepper black and light grey.
100-105	Gravel and very coarse sand, average grain size about 2 mm, varies from ½-4 mm.
105-111	Gravel, sandy
111-115	Shale, N5, medium grey, slightly micaceous and some black carbonaceous flecks
115-120	Shale, 5Y 5/1, medium grey, as above
120-123	Quartzite, hard, dark reddish brown color under microscope, can't use Munsell chart because of powder on surface. Extremely finely crystalline in matrix cementing quartz and quartzite grains to 0.25 mm across. Some pyrite.
123-134	Shale, silty and sandy, with stringers of hard quartzite as above, slightly micaceous, 5Y 5/1, grey.
134-152	Sandstone, 5Y 5/1, grey and black salt and pepper, unconsolidated; black chert about 20%, vein and crystalline quartz 80%, some greenish grains, rare reddish grains; grains angular to subrounded, average subangular to subrounded, well sorted, 0.2 to 0.3 mm (fine to medium grained). Water-bearing. 2 hour bail test conducted.
152-175 Total depth	Shale, 5Y 4/1, dark grey, micaceous, some pyrite grains and black carbonaceous flecks. Some coally carbonized wood at 170 ft.

RCA 65-2

NW 1/4, Lsd, 5, Sec. 29, Tp. 83, R. 23, W. 5th Mer.
Elevation: 2,115 feet (levelled) Mercier farm

Cumulative depth (feet)	Description
0- 10	Till, 2.5Y5/2, greyish brown, abundant pebbles, matrix clayey, micaceous
10- 15	Fine gravel, 5Y 7/3, pale yellow matrix (sand), sand matrix .2-.4 mm size (fine to medium micaceous sand)
15- 20	Fine gravel, 5Y 7/3, pale yellow matrix (sand), sand matrix as above, gravel pebbles up to 1 1/2" in sample (whole)
20- 25	Gravel as above, very little sand
25- 32	Gravel and sand as at 10-15 ft.
32- 40	Sand, 5Y 7/3, pale yellow, 0.2-0.5 mm (fine to medium sand), gravelly, micaceous (muscovite flakes), some biotite. Grains are subangular to subrounded, fairly well sorted
40- 45	Sand, as above, more gravelly (about 40% gravel)
40- 50	Sand as at 32-40, gravel < 5%
50- 55	Gravel, very little sand. Pebbles up to 3/4" in sample (broken)
55- 57	Sandy gravel (no sample)
57- 63 Total depth	Shale, soft clayey micaceous, ironstone fragments in sample. Shale is slightly carbonaceous. 5Y 4/1,dark grey.

RCA 65-3

Lsd. 10, Sec. 22, Tp. 83, R. 24, W. 5th Mer.
Elevation: 2,125 feet (barometer) Lac Cardinal Provincial Park

Cumulative depth (feet)	Description
0- 3	Clay, 2.5Y 5/2, greyish brown, micaceous, a few scattered sand grains and pebbles
3- 15	Clay (till?), sandy and pebbly, 2.5Y 5/2, greyish brown, micaceous, abundant white chalky opaque grains of gypsum? (don't fizz). Possibly a reworked till.
15- 20	Gravel,sandy, pebbles to 3/4" in sample, glacial, although pebbles typical of the Grimshaw gravels predominate. Glacial igneous pebbles show up mainly in sand fraction. Sand is fine to medium to coarse, poorly sorted, grains of chalky white gypsum.
20- 25	Clay till, 2.5Y 4/2, dark greyish brown, micaceous with white chalky gypsum grains, wood fragments. Not very stony.

Cumulative depth (feet)	Description
25- 30	Clay till, 5Y 4/1, dark grey, slightly micaceous, not very stony
30- 55	Clay till, 5Y 4/1, dark grey, micaceous, very few stones (looks like shale), non-calcareous
55- 60	Sand, 2.5Y 6/2, light brownish grey, 0.2 to 0.3 mm grain size, 0.4 rare, average 0.2, fine sand. Fair sorting, subrounded to subangular, principally white quartz grains > 90%. Remainder mainly dark chert. White mica almost nil (only 1 flake noticed); black, brown, and green mica present but not abundant. Unusual number of long thin broken quartz crystals, both clear and amber colored. Also long thin dark brown broken crystals.
60- 65	Sand, 2.5Y 5/2, greyish brown as above, scattered grains of frosted well rounded quartz up to 1 mm in size. Scattered grains to 4 mm of chert and quartz.
65- 70	Sand, 2.5Y 5/2, greyish brown, composition as above, but grain size slightly coarser, 0.2 to 0.6 mm (fine to medium to coarse) sand. Average about 0.3 mm (medium sand). Coarsest portion in lower 1 ft. but no separate sample. No definite glacial grains noticed.
70- 74 Total depth	Shale, 5Y 5/1, grey, finely micaceous (white mica), non-calcareous.

RCA 65-5

NW 1/4, Lsd. 5, Sec. 20, Tp. 83, R. 23, W. 5th Mer.
Elevation: 2,042 feet (barometer)

Cumulative depth (feet)	Description
0- 5	Clay, 10YR 3/1, very dark grey (brownish cast), with chalky white gypsum grains, few scattered pebbles.
5- 12	Clay till, 5Y 5/1, grey (olive cast), stony
12- 15	Gravel and sand, 2.5Y 6/2, light brownish grey, (sand), glacial; sand fraction dominantly quartz grains > 90%. Gravel fractions dominantly Grimshaw gravel rock types, but some glacial igneous. Pebbles to 1" in sample (whole). Grains of white chalky gypsum. No mica.
15- 16	Glacial gravel, as above, very little sand.
16- 40 Total depth	Clay shale, 5Y 5/1, grey (olive cast), soft, slightly micaceous, non-calcareous.

RCA 65-6

NE 1/4, Lsd. 8, Sec. 13, Tp. 84, R. 24, W. 5th Mer.
Elevation: 2,166 feet (barometer) Tom Case

Cumulative depth (feet)	Description
0- 5	Clay, sandy (extremely fine silt?), 10YR5/2, greyish brown, loose textured slightly micaceous (till?)
5- 10	Clay till 5Y 5/2 olive grey, slightly micaceous, chalky white gypsum grains
10- 30	Till as above 5Y 5/1 grey (or 4/1 dark grey) (olive cast) with gypsum grains
30- 47	As above, but with only a very few gypsum grains (cave ?)
47- 50	Sandy gravel, glacial, no mica
50- 55	Clay till, 5Y 5/1, gravelly
55- 65	Sandy gravel, glacial (?). Predominantly pebbles typical of Grimshaw gravels and locally derived bedrock (mainly ironstone). Shield-type igneous pebbles rare (only 2 noticed in 60-65 ft. sample) but purple Athabasca-type sandstone common. No mica in sand fraction (sand fraction 2.5Y 7/4 pale green).
65- 75	Silty sand, very fine to fine 5Y 6/3 pale olive, micaceous flakes common (fine to medium size), mainly quartz sand, some black chert grains
75-125	Silt 5Y 6/2, light olive grey, micaceous as above. Varying to 5YR5/4 reddish brown silt at intervals from 75 to 100 ft. Some carbonaceous banding.
125-128	Silt 5Y 5/1 grey (olive cast), finer than before, argillaceous, micaceous as above
128-134	Sandy gravel, 5Y 5/2 olive grey (sand fraction), sandy fraction 0.2 to 0.5 mm (medium sand) (average $\sim$ 0.3) muscovite flakes common; heterogeneous mixture of grains and pebbles. In sand fraction about 10 to 12% black chert subangular; quartz subangular to subrounded about 80%; 10% in other grains, ironstone and colored grains of chert or quartzite and opaque white chert; gravel pebbles to $>$ 1" in sample, Grimshaw gravel type.
134-135	Silt 5Y 6/1, grey (olive cast), micaceous as at 75-125 feet, a few carbonaceous bands
135-140 Total depth	Silt 10YR5/1 grey (brownish cast), very micaceous, carbonaceous banding, some coally fragments; some fine argillaceous silt with rusty banding.

RCA 65-7

SW 1/4, Lsd. 10, Sec. 16, Tp. 84, R. 24, W. 5th Mer.
Elevation: 2,135 feet (barometer)

Cumulative depth (feet)	Description
0- 2 1/2	Soil
2 1/2-17	Clay till, 2.5Y 5/2, greyish brown, quite stony (and silt and sand grains), white chalky gypsum grains. Some mica flakes.
17- 20	Gravel, with clayey sand matrix
20- 34	Clean gravel, very little sand. Pebbles to 3/4" in sample.
34- 35	Clay, 2.5Y 6/4, light yellowish brown, fine micaceous
35- 41	Clean gravel, some medium sands. Pebbles to 3/4" in sample.
41- 42	Sand, 5Y 6/2, light olive grey, fine to medium, micaceous. No sample.
42- 59 1/2	Sandy gravel, 5Y 6/3, pale olive, fine to medium grained, minor mica , 10% black chert, 80% quartz grains, 10% colored chert and quartzite and ironstone, etc.
59 1/2-60	Clay, 2.5Y 5/2, greyish brown, finely micaceous.
60- 62	Clay shale, very soft, 5Y 5/2, olive grey, slightly finely micaceous, could be clay.
62- 65	As above, some laminations; also streaks of N 4/0 dark grey, very fine sandy silt, micaceous, carbonaceous & scattered white opaque grains
65- 68 Total depth	Sandstone, 5Y 4/1, dark grey (olive cast), loosely consolidated, silty, poorly sorted, grain sizes from about 0.01 or less to 0.2 mm (silt to very fine to fine sand), some grains to 0.3 mm (medium sand); micaceous (unwashed sample). Washed sample grain size 0.1 to 0.3 mm, high mica about 2 to 3% black and green and brownish mica and chlorite; 10% black chert, about 75% quartz grains, rest different colored grains of various types. Grains are mainly subangular to subrounded.

RCA 65-11

SE 1/4, Lsd. 4, Sec. 6, Tp. 83, R. 23, W. 5th Mer.
Elevation: About 1,955 feet

Cumulative depth (feet)	Description
0- 5	Clay, 5Y 5/1, grey (olive cast), with opaque white gypsum grains, some silty clay, brownish (varved clay)
5- 12	Silt, 5Y 6/3, pale olive, finely micaceous, scattered sand grains; small crystals white opaque gypsum
12- 15	As above, but many sand grains and small pebbles (silt till)
15- 25	Silt till, clayey, 2.5Y 4/2, dark greyish brown. Oxidized. Still gypsum crystals.
25- 30	Clay silt till, 5Y 4/1, dark grey (olive cast)
30- 95	As above but clay till, although still much silt also.
95- 97	Shale, 2.5Y 5/1, grey (slight brownish cast) finely micaceous fissile shale with carbonaceous flakes, non-calcareous. Also soft non-fissile clay shale.
97- 98 Total depth	Mudstone, 5Y 4/1, dark grey (olive cast), with carbonaceous flecks, hard, non-calcareous, non-fissile, siliceous cement (?) Core barrel 2" recovery.

No water. Depth to water 22 feet one month later.

RCA 65-12

Lsd. 4, Sec. 1, Tp. 82, R. 26, W. 5th Mer.
Elevation: About 2,025 feet

Cumulative depth (feet)	Description
0- 5	Soil profile.
5- 10	Clay till, silty, 2.5Y 5/3, greyish brown with olive cast, mainly sand grains. Rare pebbles.
10- 20	Till, 5Y 5/1, grey (olive cast), as above but slightly more pebbles.
20- 60	Clay till, 5Y 4/1, dark grey (olive cast), slightly micaceous.
60- 85 Total depth	Shale, N4 dark grey, (slight olive cast in top 10 ft.), slightly calcareous, poorly fissile, some whitish gypsum (?) patches. A few pebbles (probably caved).

No water.

RCA 65-13

NE 1/4, Lsd. 16, Sec. 11, Tp. 86, R. 24, W. 5th Mer.
Elevation: 2,080 feet

Cumulative depth (feet)	Description
0- 5	Clay, 5Y 5/1, grey (olive cast), finely micaceous. No stones.
5- 13	Clay till, silty, 2.5Y 5/2, greyish brown, slightly finely micaceous.
13- 25	Silt, argillaceous, 2.5Y 5/2, greyish brown, finely micaceous. (No sand grains or pebbles.)
25- 30	Silty clay, 5Y 4/1, dark grey (olive cast), fine micaceous, gradational from above, some gypsum crystals (selenite)
30- 35	Clay, 5Y 4/1, dark grey (olive cast), fine micaceous, gradational from above.
35- 43	Shale, N4, dark grey, finely micaceous, slightly fissile, non-calcareous
43- 45	Sandstone, N5, grey, silty, very fine, micaceous, grains to 0.1 mm (some to 0.2 mm), non-calcareous, loosely consolidated, porosity fair; fairly well sorted, subangular to subrounded grains.
45- 47	Sandstone, 5Y 5/1, grey (olive cast), silty, much mica (muscovite) flakes, to 0.4 mm in dark carbonaceous layers to 1/4" thick, loosely consolidated, grain size as above, non-calcareous, fair porosity.
47- 49 Total depth	Silt, 5Y 5/2, olive grey, finely micaceous argillaceous as at 13-25 ft.

Depth to water 14 feet. Water probably mainly from 43 to 47 feet.

RCA 66-10

Lsd. 16, Sec. 36, Tp. 83, R. 24, W. 5th Mer.
Elevation: 2,146 feet (levelled)
Samples for RCA 66-10 were dried on a Coleman stove at the drill site and many samples are reddish from overheating. Consequently, colors are not always true and therefore color is not always indicated in descriptions.

Cumulative depth (feet)	Description
0- 10	Clay till, 2.5Y 5/2, greyish brown, stony (probably reworked) (0-5 sample probably overwashed, looks like sandy glacial gravel).
10- 27	Clay till, slightly silty, 2.5Y 5/2, greyish brown, not many stones or sand grains. Abundant opaque white gypsum crystals.
27- 30	Gravel, sandy, sand is coarse to very coarse, 1/2 to 2 mm.
30- 35	Sand, dirty, silty, poorly sorted, very fine to fine, scattered pebbles and coarser sand grains. Silt content is high, about 20 to 30%(?).
35- 50	Sand, 2.5Y 6/2, light brownish grey, micaceous, very fine to medium (washed sample). Gravelly streaks.
50- 55	Fine sandy gravel.
55- 60	Gravelly sand, very silty 10YR6/3, pale brown,(unwashed sample). Sand poorly sorted, very fine to fine to medium to coarse. Ratio of sand:gravel:silt about 1:1:1.
60- 65	Gravel, silty, sandy as above but silt:sand:gravel: ratio about 1:2:3. (Washed sample - all silt washed out.)
65- 66	Clay, sandy, 2.5Y 6/3, light yellowish brown.
66- 70	Gravel, fine, some medium to coarse sand.
70- 75	Sand, medium to coarse to very coarse, minor very fine to fine sand, finely gravelly.
75- 80	Gravel, sandy
80- 85	Sand, very fine to fine, some medium coarse sizes, micaceous mainly subangular, fair sorting, white mica and green (chlorite) and brown. Black chert < 5%. Numerous colored grains.
85- 93	Sand and gravel, 5Y 7/3, pale yellow, sand very fine to fine to medium, some coarse sand. Composition as above.
93- 97 1/2	Sandstone, 5Y 5/1, grey, dirty, finely silty, very fine to fine, to sandy siltstone, slightly micaceous.

RCA 66-11

250 feet northwest of RCA 66-10
Elevation: 2,147 feet (levelled)

Cumulative depth (feet)	Description
0- 35	Till
35- 45	Gravel, pea size; fine sand matrix
45- 50	Sand, fine, and gravel
50- 55	Gravel, pea size and fine to coarse sand
55- 60	Sand, fine, and gravel

Cumulative depth (feet)	Description
60- 65	Sand, coarse, and gravel; some fine sand
65- 70 Total depth	Sand, fine to medium grained, some gravel

RCA 66-12

60 feet southeast of RCA 66-11
Elevation: 2,146 feet (levelled)

0- 5	No sample
5- 35	Till
35- 40	Sand, medium to coarse, some fine sand
40- 50	Sand, medium, some fine sand
50- 55	Sand, mainly coarse, and fine gravel
55- 60	As above, slightly more gravel
60- 62 1/2	No sample
62 1/2-64 Total depth	Clay, yellowish, sandy

RCA 66-13
SE 1/4, Lsd. 3, Sec. 2, Tp. 84, R. 24, W. 5th Mer.
Elevation: 2,130 feet (levelled)

Cumulative depth (feet)	Description
0- 10	Till
10- 15	Gravel and sand, fine to medium grained
15- 20	Gravel and sand, mostly fine grained
20- 25	Gravel and sand, fine to medium grained
25- 30	Gravel and sand, fine to coarse; less gravel than before
30- 35 Total depth	Sand, mainly fine to medium grained; some gravel

RCA 66-14

Lsd. 7, Sec. 29, Tp. 83, R. 23, W. 5th Mer.
Elevation: 2,090 feet (levelled)

Cumulative depth (feet)	Description
0- 15	Gravel, well compacted
15- 20	Gravel, sand and clay; gravel is coarse
20- 25	Sand and gravel
25- 27 1/2	As above, gravel is coarser
27 1/2-32 1/2	Sand and clay, sand is fine to medium grained

Cumulative depth (feet)	Description
32 1/2-35	Sand, fine to medium grained
35- 40 Total depth	Sand and silt, sand is fine grained

RCA 66-15

NW 1/4, Lsd. 16, Sec. 36, Tp. 83, R. 24, W. 5th Mer.
Elevation: 2,136 feet (levelled)

Cumulative depth (feet)	Description
0- 12	Till, yellowish brown
12- 18	Sand and gravel, some clay
18- 25	Sandy gravel, some clay
25- 31	Clean gravel
31- 35	Clay, sand and gravel
35- 37 Total depth	Sand and fine gravel, sand is fine to medium grained

Water Resources Test Hole 66-1

SW 1/4, Lsd. 8, Sec. 18, Tp. 85, R. 21, W. 5th Mer.
Elevation: 1950 feet

Cumulative depth (feet)	Description
0- 10	Clay, very silty, yellowish brown; oxidized
10- 13	Clay, very silty, transitional to dark grey; oxidized
13- 25	Clay, very silty, dark grey; unoxized
25- 27	Clay, very silty, slightly sandy, dark grey, moist
27- 60	Clay, very silty, dark grey (farmer reports snail shells at 45 ft. depth in nearby dug well)
60- 75 Total depth	Clay, non-silty, dark grey, hard drilling

Water at 25 feet but very little.

Water Resources Test Hole 66-2

W, Lsd. 2, Sec. 14, Tp. 84, R. 22, W. 5th Mer.
Elevation: 1,810 feet

Cumulative depth (feet)	Description
0- 3	Soil profile
3- 25	Clay, silty, brownish; more silty and moist at 17 to 19 ft.
25- 32	Silt, light yellowish brown, powdery when dry
32- 49	Silt, clayey, brownish grey, a few stones
49- 56	Silt, brownish, powdery when dry, quite a few stones
46- 75	Silt to very fine grained sand, greyish, dirty, poorly sorted; water
	Depth to water 56 feet.

Water Resources Test Hole 66-3

SW 1/4, Lsd. 4, Sec. 19, Tp. 84, R. 21, W. 5th Mer.
Elevation: 1,700 feet

Cumulative depth (feet)	Description
0- 2	No sample
2- 20	Clay, slightly silty, brownish grey; oxidized
20- 23	Clay, slightly silty, brownish grey, darker than before
23- 47	Clay, silty, dark brownish grey, some stones
47- 75	Clay, silty, dark grey, some stones
	Dry hole.

Water Resources Test Hole 66-4

SE 1/4, Lsd. 4, Sec. 12, Tp. 84, R. 22, W. 5th Mer.
Elevation: 1,680 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 20	Clay and silt, interlaminated, brownish grey
20- 25	Silt, yellowish brown
25- 35	Clay, slightly silty, dark grey
35- 40	Sand, gravelly, clayey, dirty; water
40- 60 Total depth	Clay, dark grey; a few pebbles
	Depth to water 26 feet.

Water Resources Test Hole 66-5

SW 1/4, Lsd. 2, Sec. 25, Tp. 84, R. 22, W. 5th Mer.
Elevation: 1,850 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 20	Clay, silty, brownish grey
20- 30	Clay, slightly silty, dark grey
30-31 1/2	Siltstone (rock), powdery, pale grey, very hard drilling
31 1/2-75	Till, dark grey, few pebbles

Dry hole.

Water Resources Test Hole 66-6

Lsd. 16, Sec. 2, Tp. 84, R. 22, W. 5th Mer.
Elevation: 1,720 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 9	Silt, dry, yellowish brown
9- 20	Silt, moist, yellowish brown; layers of dark grey clay in lower 4 ft.
20- 30	Clay, silty, brownish grey; or interlayered clay and silt
30- 40	Silt to clayey silt
40- 42	Sand, fine grained, brownish, dirty; fairly well sorted
42- 50 Total depth	Till, silty to locally sandy, dark grey, very clayey

Depth to water 8 ft.

Water Resources Test Hole 66-7

S 1/2, Lsd. 4, Sec. 15, Tp. 81, R. 26, W. 5th Mer.
Elevation: About 1,940 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 38	Clay till, slightly micaceous, silty, 5Y 5/2, olive grey
38- 45	Sandy silt, 5Y 5/3, olive, poorly sorted, some grains to 0.2 mm, very fine (water)

Cumulative depth (feet)	Description
45- 75 Total depth	Clay till, 5Y 4/1, dark grey (olive cast), with sand grains and pebbles not common and silt sizes practically lacking.
	Depth to water 18 1/2 feet. Water from 38-45 feet.

Water Resources Test Hole 66-8

E 1/2, Lsd. 2, Sec. 26, Tp. 80, R. 1, W. 6th Mer.
Elevation: About 1,905 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 13	Silt, 2.5Y 5/2, greyish brown, fine
13- 21	Silt, 5Y 5/1, grey (olive cast), finely micaceous, gypsum crystals (selenite) (silt size slightly coarser than above)
21= 31	Silt, 5Y 4/1, dark grey (olive cast), slightly sandy (very fine)
31- 36	Clay, 5Y 4/1, dark grey (olive cast), smooth, slightly calcareous
36- 47	Silt, argillaceous, 5Y 4/1, dark grey (olive cast)
47- 51 Total depth	Clay till (?), 5Y 4/1, dark grey (olive cast), not very stony. Could be a clay or soft shale. Probably a lacustro till.
	Terminated hole when encountered rock. Depth to water next day 23 1/2 ft.

Water Resources Test Hole 66-9

SW 1/4, Lsd. 12, Sec. 34, Tp. 82, R. 1, W. 6th Mer.
Elevation: About 2,145 feet

Cumulative depth (feet)	Description
0- 9	Silt, yellowish brown
9- 14	Till, yellowish brown (oxidized), slightly silty
14- 75 Total depth	Till, dark grey, clayey
	Dry hole.

Water Resources Test Hole 66-10

SW 1/4, Lsd. 3, Sec. 4, Tp. 83, R. 1, W. 6th Mer.
Elevation: 2,140 feet

Cumulative depth (feet)	Description
0- 3	Sand, greyish brown, very fine grained
3- 5	Sand, yellowish brown, very fine grained
5- 9	Sand, orange-brown, very fine to fine grained
9- 16	Clay, dark grey, no stones
16- 75 Total depth	Till, dark grey, much like clay above; few stones
	Dry hole

Water Resources Test Hole 66-11

Lsd. 16, Sec. 15, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,180 feet

Cumulative depth (feet)	Description
0- 3	Clay, silty
3- 16	Till, brownish; oxidized
16- 38	Till, dark grey, few stones
38- 43 Total depth	Till, stony; hit rock and quit drilling
	Dry hole.

Water Resources Test Hole 66-12

SE 1/4, Lsd. 16, Sec. 26, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,225 feet

Cumulative depth (feet)	Description
0- 3	No sample
3- 10	Till, brownish; oxidized
10- 43	Till, dark grey, few stones
43- 55	Till, dark brownish grey, hard, fairly stony
55- 75 Total depth	Clay, silty, olive grey; water
	Depth to water 12 feet.

Water Resources Test Hole 66-13

NE 1/4, Lsd. 2, Sec. 14, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,165 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 7	Till, brownish
7- 17	Till, greyish brown
17- 30	Till, dark grey with brownish tinge
30- 33	Till, very stony
33- 48	Gravel, dry, mixed with clay (preglacial?)
48- 51	Gravel, as above, but greater percentage of clay
51- 59	Wet (soupy) material, dark grey (silty clay)
59- 75 Total depth	Till(?), dark grey, very few pebbles
	Hole was "blowing" after drilling. Caved in at 32 feet.

Water Resources Test Hole 66-14

SE 1/4, Lsd. 16, Sec. 22, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,190 feet

Cumulative depth (feet)	Description
0- 12	Till, brownish
12- 14	Till, dark brownish grey
14- 31	Till, dark grey
31- 60 Total depth	Till, very stony, gravelly; gravel at 32-36 ft. and at 55-60 ft.
	Samples very poor; gravel appears clayey. Depth to water 8 feet.

Water Resources Test Hole 66-15

Lsd. 4, Sec. 13, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,160 feet

Cumulative depth (feet)	Description
0- 3	No sample
3- 10	Till, brownish
10- 23	Till, dark brownish grey
23- 27	Till, dark brownish grey
27- 35	Gravel, dry, sandy clay matrix
35- 40	Sand, fine to medium, wet, dirty, some gravel; water bearing
40- 50 Total depth	Till, hard, stony
	Caved in at 27 feet.

Water Resources Test Hole 66-17

SE 1/4, Lsd. 9, Sec. 28, Tp. 84, R. 2, W. 6th Mer.
Elevation: 2,260 feet

Cumulative depth (feet)	Description
0- 10	Till, brownish
10- 27	Till, brownish grey
27- 57	Till, dark grey with brownish tinge
57- 75 Total depth	Till, dark grey
	Dry hole.

Water Resources Test Hole 66-18

SE 1/4, Lsd. 1, Sec. 5, Tp. 85, R. 2, W. 6th Mer.
Elevation: 2,220 feet

Cumulative depth (feet)	Description
0- 8	Clay, silty, brownish, dry
8- 10	Sand, clayey, dirty; water
10- 18	Till, brownish
18- 75 Total depth	Till, dark grey
	Depth to water 10 feet.

Water Resources Test Hole 66-19

SE 1/4, Lsd. 9, Sec. 4, Tp. 85, R. 2, W. 6th Mer.
Elevation: 2,240 feet

Cumulative depth (feet)	Description
0- 5	No sample
5- 18	Till, brownish
18- 25	Till, dark greyish brown
25- 73	Till, dark grey, very few stones
73- 75 Total depth	Till, dark grey, stony.
	Dry hole.

Water Resources Test Hole 66-25

Lsd. 8, Sec. 9, Tp. 82, R. 2, W. 6th Mer.
Elevation: 2,160 feet

Cumulative depth (feet)	Description
0- 2	No sample
2- 8	Sand, fine grained to silt, yellowish brown; gypsum crystals
8- 12	Till, silty, yellowish brown; gypsum crystals
12- 13	Till, silty, brownish grey; gypsum crystals
13- 49	Till, clayey, dark grey; gypsum crystals; brownish tinge to 17 ft.
49- 52	Silt to very fine grained sand, clayey, poorly sorted; olive grey
52- 55	Clay, silty, damp
55- 63	Sand, very fine grained, silty, clayey, damp
63- 64	Sand, fine grained, fairly clean, yellowish orange in color
64- 70 Total depth	Shale, dark grey, with gypsum crystals.
	Depth to water 45 feet.

Test Hole Drilled by McAuley Drilling - August, 1966

NW 1/4, Lsd. 5, Sec. 33, Tp. 83, R. 22, W. 5th Mer.
Elevation: About 1,860 feet

Cumulative depth (feet)	Description
0- 5	Clay, 5Y 5/1, grey, smooth
5- 20	Silt, 5Y 5/2, olive grey, slightly micaceous, opaque white gypsum crystals at 15 to 20 ft.
20- 25	Silt, 5Y 5/3 olive, very fine sandy
25- 30	As above and clay, 5Y 5/1, grey, smooth; sandy silt varies to silty sand, very fine
30- 35	Silt as above, slightly sandy, no clay
35- 40	Silty sand and sandy silt as above, no clay
40- 60	Silt as above, slightly sandy, abundant small opaque white gypsum crystals. One of these crystals shows clear core with white opaque coating, indicating that the opaqueness could be due to weathering (oxidation)
60- 76	Silt, slightly sandy, as above, no gypsum crystals
76- 83	Sand and gravel, glacial, poorly sorted; some till fragments
83-100	Silty clay till, 5Y 5/1, grey, not many stones
100-103	Gravel, glacial, fine, mixed with till (water)
103-120 Total depth	No sample, till

Unsuitable - yield low, about 1 1/2 igpm. Not enough head. Depth to water 90 feet.

Appendix III. Grain size analyses of surficial materials

Mechanical analyses of different sediments are shown in plotted form in figures 12, 39, and 40. The phi scale (Krumbein, 1934) has been used in the plots. For comparative purposes, the Wentworth grade scale (Wentworth, 1922) and the grade scale used by the Soil Survey of Alberta are also shown.

In attempting to classify the curves obtained, various statistical parameters may be applied. A discussion of the significance and meaning of these may be found in Folk, 1965. There are four basic parameters:

1) Measures of average grain size.

The average grain size is here shown by means of the phi median, $Md\O = \O 50$ and by the graphic mean, $Mz = \frac{(\O 16 + \O 50 + \O 84)}{3}$. The latter is more representative of the average grain size but is not always obtainable without extrapolation of the plotted curve.

2) Measures of uniformity.

These measures give approximately the degree of sorting of a sediment. The degree of sorting is here given by either the graphic standard deviation, $\sigma_G = \frac{(\O 84 - \O 16)}{2}$ or by the inclusive graphic standard deviation, $\sigma_1 = \frac{\O 84 - \O 16}{4} + \frac{\O 95 - \O 5}{6/6}$.

A classification of sorting, based on different values of σ_1 is as follows:

Very well sorted	(VWS),	σ_1 0.35Ø
Well sorted	(WS),	$\sigma_1 = 0.35$ to 0.5 Ø
Moderately sorted	(MS),	$\sigma 1 = 0.5$ to 0.71 Ø
Moderately poorly sorted	(MPS),	$\sigma 1 = 0.71$ to 1.0 Ø
Poorly sorted	(PS),	$\sigma 1 = 1.0$ to 2.0 Ø

Very poorly sorted	(VPS),	$\sigma_1 = 2$ to $4\,\emptyset$
Extremely poorly sorted	(XPS),	$\sigma_1 = \quad 4\,\emptyset$

If σ_1 is unobtainable, due to overly long extrapolations of the plotted curve, approximately the same answer may be obtained using σ_G.

3) Measures of skewness or assymetry

These measures indicate the symmetry of the plotted curve. For example a curve which has a long "tail" of fines is called fine skewed. The measure for skewness used here is the inclusive graphic skewness, $Sk_1 = \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{2(\emptyset 84 - \emptyset 16)} + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{2(\emptyset 95 - \emptyset 5)}$.

For different values of Sk_1, the skewness is as follows:

Symmetrical	(Sym)	$Sk_1 = 0.00$
Strongly fine skewed	(SFSk)	$Sk_1 = +1.0$ to 0.3
Fine skewed	(FSk)	$Sk_1 = +0.3$ to 0.1
Near-symmetrical	(N.Sym)	$Sk_1 = +0.1$ to -0.1
Coarse skewed	(C.Sk)	$Sk_1 = -0.1$ to -0.3
Strongly coarse skewed	(S.C.Sk)	$Sk_1 = -0.3$ to -1.0

4) Measures of kurtosis or "peakedness"

These measures indicate whether sorting is better in the central part of a plotted curve or in the "tail" ends. The measure for kurtosis used here is the graphic kurtosis, $K_G = \frac{\emptyset 95 - \emptyset 5}{2.44(\emptyset 75 - \emptyset 25)}$

For different values of K_G, the kurtosis is as follows:

Very platykurtic	(VPl)	$K_G \quad 0.67$
Platykurtic	(Pl)	$K_G = 0.67$ to 0.9 (flat peak, tails better sorted than central part)

Mesokurtic	(Me)	K_G = 0.9 to 1.11
Leptokurtic	(L)	K_G = 1.11 to 1.50 (central part better sorted than tails)
Very leptokurtic	(VL)	K_G = 1.5 to 3.0
Extremely leptokurtic	(XL)	K_G = 3.00

Table 6 is a tabulation of grain size parameters of clastic sediments in the Grimshaw-Cardinal Lake area.

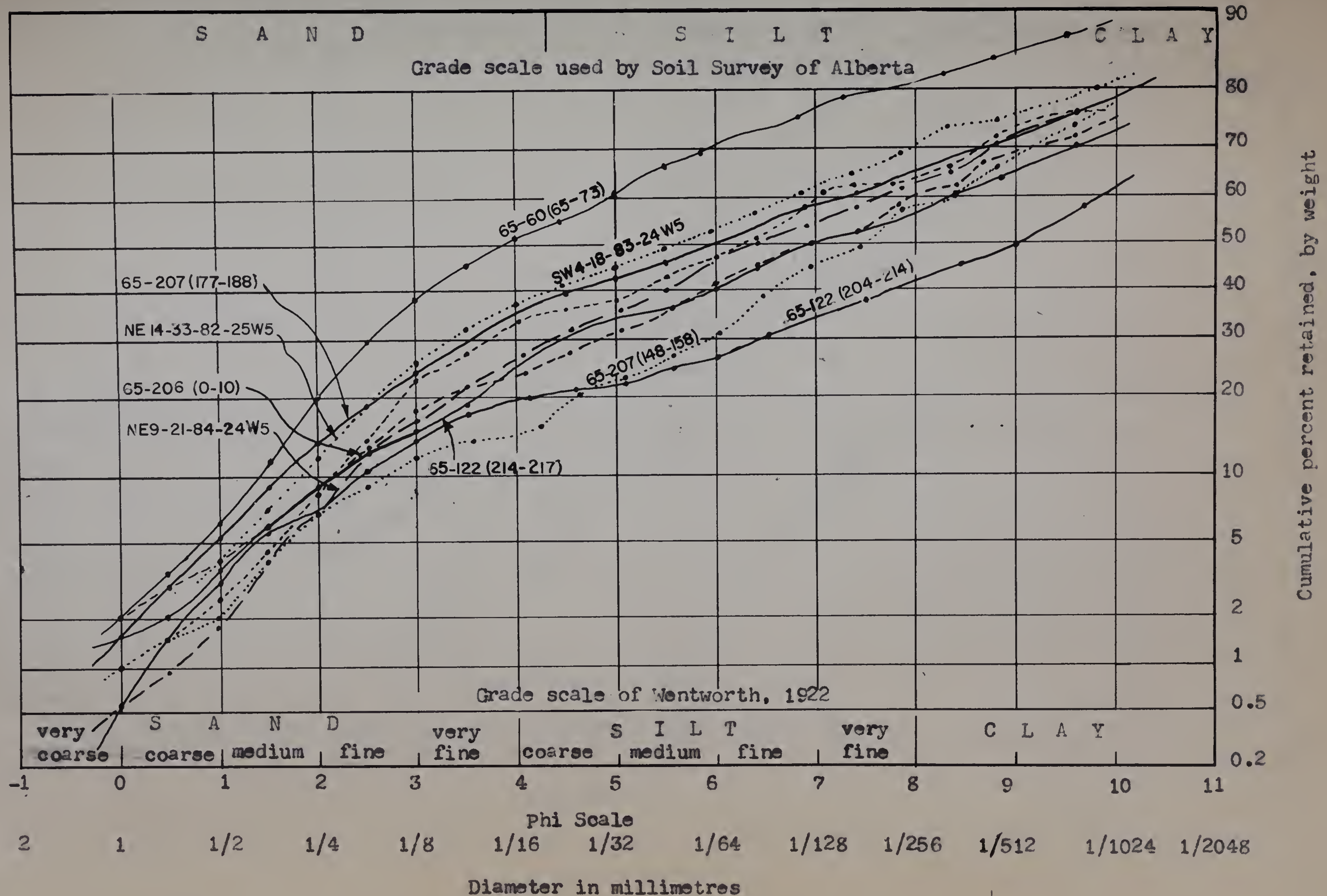


Figure 39 - Grain size analyses of tills (< 2 mm. size fraction only)

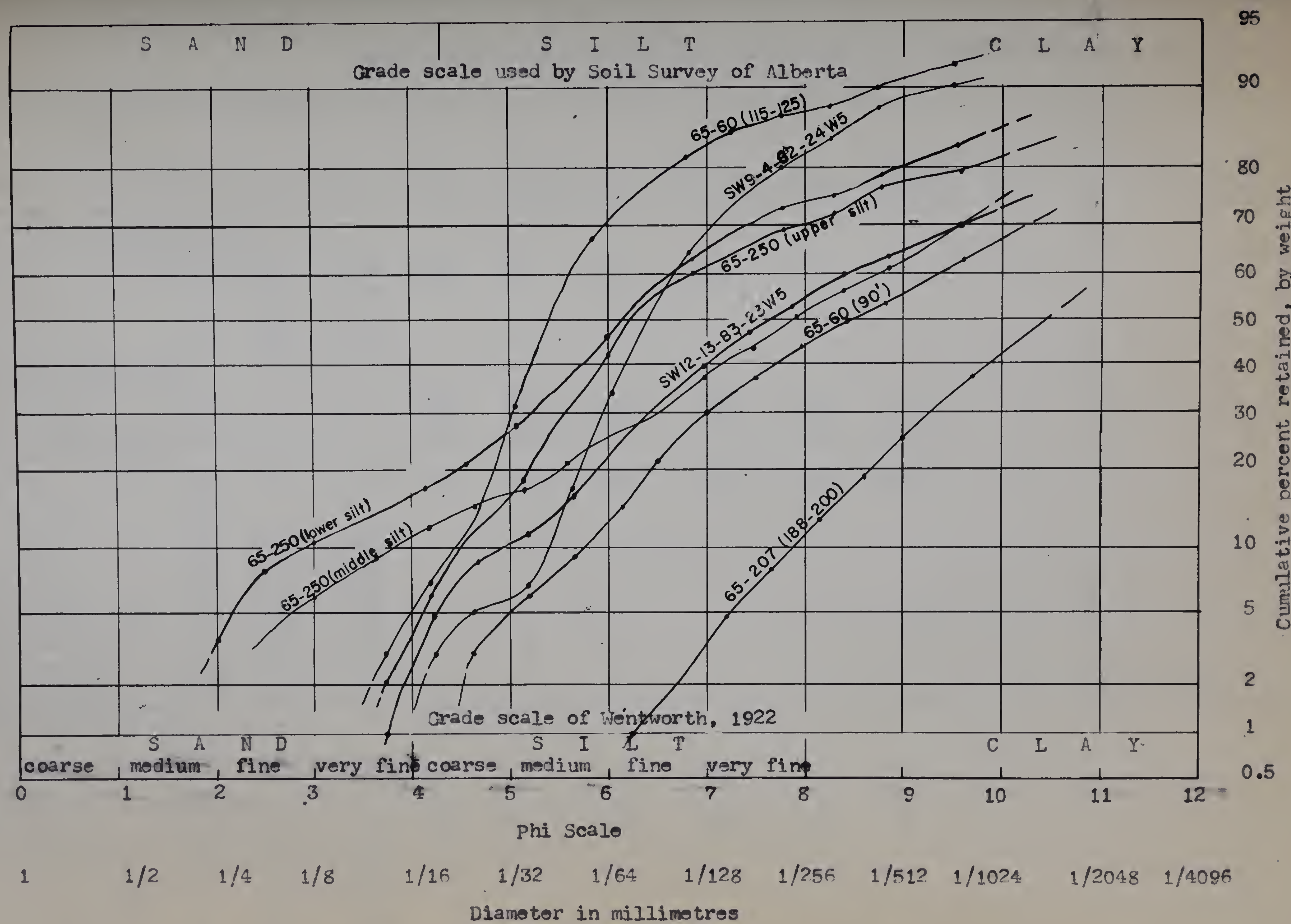


Figure 40 - Grain size analyses of lacustrine silts and clays.

Table 6. Grain size parameters for sediments analyzed, Grimshaw-Cardinal Lake area*

Locality	MdØ	Mz	σ_G	σ_1	Sorting	Sk_1	Skewness	K_G	Kurtosis	Per cent gravel	Per cent sand	Per cent silt	Per cent clay	Ratio sand/silt + clay	Sediment type (Folk, 1965)
A) Grimshaw-type gravels and sands															
66-11 (50-55')	-0.41	-0.47	1.20	1.68	PS	0.19	FSk	1.7	VL	34	60	6	-	10/1	Sandy gravel
66-11 (65-70')	0.40	-0.20	2.20							34	65	1	-	65/1	Sandy gravel
SW 13-18-83-23-W.5	-3.95	-3.62	1.15							91	9	1/2	-	20/1	Gravel
W 5-18-84-23-W.5	0.18	0.05	1.15							21	78	1	-	100/1	Gravelly sand
B) Glacial sands and gravels															
14-20-82-23-W.5	0.75	0.22	2.15	1.98	PS	-0.41	SCSk	1.2	L	27	72	0.8	-	100/1	Gravelly sand
E1-30-82-24-W.5	0.25	-0.55	3.15	2.64	VPS	-0.35	SCSk	0.64	V.Pl	40	59	0.7	-	100/1	Gravelly sand
C) Tills (< 2 mm fraction)															
65-60 (65-73')	3.80	4.78	3.47	3.51	VPS	0.44	SFSk	1.04	Me	1	52	29	18	1	Slightly gravelly muddy sand
65-122 (204-214')	9.00									1	20	22	57	1/4	Slightly gravelly muddy sand
65-122 (214-217)	6.90	7.20	4.25							1	24	30	44	1/3	Slightly gravelly muddy sand
65-206 (0-10')	6.90	7.03	4.30							1	23	36	40	1/3	Slightly gravelly muddy sand
65-207 (148-158)	5.95	7.48	3.23							1	14	43	42	1/6	Slightly gravelly muddy sand
65-207 (177-188')	7.50	6.35	4.35							1	35	30	34	1/2	Slightly gravelly muddy sand
NE 14-33-82-25-W.5	6.25	6.66	4.24							1	32	31	36	1/2	Slightly gravelly muddy sand
SW 4-18-83-24-W.5	5.60	6.20	4.20							1	36	33	30	1/2	Slightly gravelly muddy sand
NE 9-21-84-24-W.5	6.40	6.73	4.00							1	26	36	37	1/3	Slightly gravelly muddy sand
D) Lacustrine clays and silts														clay/silt	
65-50 (90')	8.6									0	0	44	56	1	Mud (silty clay)
65-60 (115-125')	5.4	5.76	1.21	1.69	PS	0.52	SFSk	2.1	VL	0	5	82	13	1/5	Silt
65-207 (188-200')	10.5									0	0	11	89	8/1	Clay
SW 9-4-82-24-W.5	6.4	6.75	1.32	1.78	PS	0.44	SFSk	2.0	VL	0	1	82	18	5/1	Silt
SW 12-13-83-23-W.5	7.75	8.23	2.83							0	3	21	76	4/1	Clay
NE 9-21-84-24-W.5 (u)	6.2	7.27	2.80							0	4	66	30	1/2	Silt
NE 9-21-84-24-W.5 (mid)	7.9	7.93	3.05							0	11	41	48	1	Sandy mud
NE 9-21-84-24-W.5 (l)	6.15	6.62	2.85							0	16	58	26	1/2	Sandy silt

*Underlined figure or letter indicates that it is based on calculation from extrapolated values (lengthy extrapolations have not been made).

Appendix IV. Carbonate analyses of surficial materials by Chittick apparatus (ref. Dreimanis, 1962

Locality and location		Footage	Type of sediment	% dolomite	% calcite	calcite:dolomite ratio
65-60	SW-15-20-82-23-W.5	65-73	till	3.2	1.2	0.38
65-60	"	90	lacustrine clay	2.8	1.0	0.36
65-60	"	115-125	lacustrine silt	11.3	5.8	0.52
65-230	SW-4-18-83-24-W.5		till	2.7	1.0	0.37
65-250	NE-9-21-84-24-W.5		till	1.8	0.5	0.28

Appendix V. Water-well records, Grimshaw-Cardinal Lake area

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
14	22	81	24	D	48x48	1100	52	41	Gr	0-20 silt, 20-32 gr; water level fluctuates with river level
14	22	81	24	C	6 1/4	1100	52	41	Gr	0-20 cl, 20-52 gr & some sd. Completed with 4 ft. of slotted casing. Surged to develop. Bailed at 20 igpm for 2 1/2 hrs., drawdown 0.2 ft.
16	8	81	25	D	60x60	1780	12	7	Cl	0-12 cl; situated 10 feet from creek. Chemical analysis available.
16	8	81	25	D		1800	shallow			
13	15	81	25	B	18		107	62	Q	0-100 cl, 100-107 q
11	19	81	25			1925	150			0-150 cl; "dry" hole
15	19	81	25	Dr	4	1950	92	F	Q	Flows at about 1 igpm. Chemical analysis available.
13	20	81	25	R		1940	270	F		0-80 cl, 80-150 q, 150-260 cl, 260-270 sd(?); flows at about 10 igpm. Chemical analysis available.
13	21	81	25	Dr		1900				0-40 blue cl, 40-400 sd & cl; 3 wells drilled to 300 to 400 ft. All "dry".
4	26	81	25	B		1875	100		Q	Q & gumbo; insufficient supply in summer. Chemical analysis available.
13	26	81	25	B	36	1880	97		Sd	Chemical analysis available.
5	28	81	25	J	3	1940	271	F		0-268 cl & silt, 268-270 rock; flow at about 15 igpm. Chemical analysis available.
13	29	81	25	C	4	1995	93	F		0-61 cl, 61-76 sd, 76-93 cl; flow at about 5 igpm. Chemical analysis available.
13	31	81	25	D		2005	50	40	Gr	0-50 blue cl, 50 gr
2	32	81	25	J	3	1970	323	F		0-230 blue cl & boulders, 230-243 sh, 243-244 hard rock, 244-274 ss, 274-275 hard rock, 275-323 ss; flow at about 20 igpm.
8	32	81	25	Dr	4	1970	328	F		0-300 cl, 300-328 gr. Chemical analysis available.
8	34	81	25	B	36x36	1950				Well is plugged off.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
5	35	81	25	Dr	5	1950	150	29		0-85 cl, 85-150 cl & q in alternate 5-ft. intervals. Chemical analysis available.
15	35	81	25	Dr	3	1950	480	F		Chemical analysis available.
14	36	81	25			1900	110		Q	0-45 cl & gr, 45-50 cl, 50-80 sandy cl, 80-90 hard cl; 90-93 sd, 93-103 hard sd, 103-115 hard cl, 115-117 cl & gr, 117-140 hard cl; well unused, not enough water.
8	25	81	26	Dr	2	1970	44	F	Gr	0-43 cl, 43 gr; Chemical analysis available.
9	25	81	26			1975	32	6		0-29 till, 29 silty sd; 48"x48" wooden cribbing dug in to 12 ft. & hole augered out. Chemical analysis available.
NE	25	81	26	R	3		34	4		
16	8	82	23	R	3	1150	24			Well unused; water level fluctuates with level of river. 3 in. casing to 24 ft." Well can't be pumped dry." Chemical analysis available.
16	15	82	23	D		1050	30	26	Gr	Chemical analysis available.
12	18	82	23		4	1850	68	10		Continuous pumping possible. Chemical analysis available.
1	19	82	23		4	1840	103	88	Gr	0-60 cl, 60-90 q, 90-98 ss, 98-101 q, 101-103 gr; well cannot be pumped dry. Chemical analysis available.
13	19	82	23		4	1860	56	27		0-25 cl, 25-56 q, 56 gr. Chemical analysis available.
16	21	82	23		36x36	1625	23	22	Black sd	0-20 blue cl, 20 sd. Chemical analysis available.
1	22	82	23	Dr		1075	87	43		0-20 cl, 20-87 gr; well would go dry as river level fell.
8	30	82	23	D		1840	50	48		0-48 cl, 48-50 q. Chemical analysis available
14	32	82	23	Dr	4	1870	74	42	Gr	0-25 cl, 25-73 q, 73-74 gr. Chemical analysis available.
NE	32	82	23	Dr		1850	73	23	Sd	0-35 cl, 35-55 sd & cl, 55-70 sd, 70-76 coarse sd
14	34	82	23	Dr	6	1760	124	110	Sd	0-100 cl, 100-107 sd, 107-142 q. Chemical Analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
NE	36	82	23	C	7	1150	83	32		0-5 cl, 5-8 sd, 8-21 gr, 21-79 sd & gr, 79-83 cl; driven casing, screen.
13	2	82	24	Dr	4	1820	275	42		0-20 cl, 20-70 sh, 70-105 cl & rocks, 105-106 gr, 106-195 blue cl, 195-235 sh, 235-236 ss, 236-275 blue cl;
										Chemical analysis available.
16	5	82	24	Dr	6	1895	94	69		Well abandoned; very dirty water. Chemical analysis available.
16	7	82	24	D	48x48	1960	80			Chemical analysis available.
16	7	82	24	Dr		1960	300	13	Black sd	
5	8	82	24	D	24x24	1925	65	15		0-65 cl; steel cribbing. Continuous pumping possible; level remains fairly constant. Chemical analysis available.
5	9	82	24	B		1925	53	52		Big stones at bottom, cl above. Chemical analysis available.
16	9	82	24	Dr	4	1895	88	55	Gr	0-60 cl, 60-68 q, 68-78 cl, 78-79 sd, 79-87 cl, 87-88 gr. Chemical analysis available.
8	10	82	24	B		1860	55		Q	0-50 cl, 50-55 q. Chemical analysis analysis available.
14	10	82	24	Dr	4	1875	200		Sd	Chemical analysis available.
10	13	82	24	Dr	4	1850	87	77	Gr	0-60 cl, 60-87 gr. Chemical analysis available.
15	14	82	24			1890	6 3	5	Gr	Chemical analysis available.
8	15	82	24		3	1880	59	0.7	Gr	
8	15	82	24			1880	56			Well has stopped flowing since it filled with sd
9	15	82	24		36x36	1900	26	19	Q	Well goes dry occasionally. Chemical analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.m	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
9	15	82	24	Dr	4	1910	60			Chemical analysis available.
1	16	82	24	Dr	6	1900	160	25		0-50 cl, 50-75 gr, 75-160 cl, rock pan; water flowed at 100 ft. & 120 ft.; was soft, turned hard. Chemical analysis available.
5	17	82	24	Dr		1970			Sd & gr	Good pumping rate possible. Chemical analysis available.
12	17	82	24		6	1990	83	80		Chemical analysis available.
1	18	82	24	Dr	4	1960	157	72	Gr	Water at 75 ft. & 90 ft. Chemical analysis available.
14	19	82	24	C		2100		50		Chemical analysis available.
14	19	82	24	Dr	2100	2100	120		Coarse sd	Chemical analysis available.
14	19	82	24	Dr		2100	117		Coarse sd	Originally dug well to 40 ft. & gravel. Chemical analysis available.
5	20	82	24	R	5	2050	135			Chemical analysis available.
8	21	82	24		4	1940	>60			Chemical analysis available.
13	21	82	24	Dr	4	2000	120	80	Fine sd	Good pumping rate possible. Chemical analysis available.
16	22	82	24	D	48x48	1930	37	26		Chemical analysis available.
16	23	82	24			1910				Chemical analysis available.
5	25	82	24	Dr	4 1/2	1920	72	40	Sd	0-20 cl, 20-40 q, 40-70 cl, 70 sd. Chemical analysis available.
4	29	82	24	Dr	4	2050	220	100		0-60 blue cl, 60-80 red cl & sd & gr, 80-170 q, 170-173 rock pan conglomerate, 173-177 q (silty), 177-220 cl & gr. Chemical analysis available.
1	30	82	24		4 1/2	2075	181	54	Loose gr	0-28 sd, 28-125 blue cl, 125-163 hard brown cl, 163-180 cemented gr, 180-181 loose gr. Chemical analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
1	30	28	24		36	2075	27	25	Q	Chemical analysis available.
	31	82	24	Dr	4.5	2125	200	78		0-10 sd, 10-149 sticky cl, 149-151 gr, 151-176 light colored cl, 176-177 black hard ss, 177-189 soft grey ss, 189-200 hard sh; no slots or screen.
	31	82	24	Dr	4.5	2125	73	69		0-15 brown cl, 15-65 sticky blue cl, 65-67 ss, 67-73 gr
9	32	82	24	C	4	2102	134	10	Gr & sd	0-6 cl, 6-127 q, 127-134 gr. Chemical analysis available.
9	32	82	24	C	4	2102	58	46		0-8 sandy cl, 8-58 gr; slotted casing driven.
11	32	82	24	Dr		2090	106	74	Gravelly sd	0-100 cl, 100 gr. Chemical analysis available.
2	33	82	24	Dr	4	2030	41			Well dry, could be partially filled in.
12	33	82	24	Dr	4	2106	92	26	Fine sd	0-87 cl, 87-90 gr, 90-92 sd, rock. Chemical analysis available.
15	34	82	24	Dr	4	2010	105	90	Sd	Continuous pumping possible. Chemical analysis available.
15	35	82	24	D	48x48	1970	38	18		Concrete cribbing for 20 ft., then 6 in. steel casing. Chemical analysis available.
15	36	82	24	C	4	1925	138	6		6-in. diam. steel culvert, then 4 in. steel casing. Chemical analysis available.
4	2	82	25	Dr	4	1950	270	0		Chemical analysis available.
9	2	82	25	Dr	6	1975	195	F		Rate was more when drilled. Chemical analysis available.
13	2	82	25	B	30	2025	53	23		Chemical analysis available.
13	2	82	25	B		2025	70			Chemical analysis available.
13	2	82	25	Dr		2025	170	F		3 inch casing. Chemical analysis available.
1	3	82	25	Dr	6	1980	168	F		Chemical analysis available.
12	5	82	25	Dr		2040				Chemical analysis available.

Location W. 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
3	6	82	25	Dr		2027	80	22	Gr	0-10 till, 10-80 blue cl, 80 gr. Chemical analysis available.
3	7	82	25	B		2025				Chemical analysis available.
8	7	82	25	Dr		2025	80		Blue cl, some gr	0-75 cl, 75-77 q, 77-80 cl; gaseous. Chemical analysis available.
14	7	82	25	Dr	6	2040	32		Gr	0-30 cl, 30-32 gr; possible to pump dry. Chemical analysis available.
16	10	82	25	48x48	48x48	2100	32	30	Gr	0-30 cl, 30-32 gr; Chemical analysis available.
14	11	82	25	B	36	2100	23		Gr	Continuous pumping possible. Chemical analysis available.
16	12	82	25	B&Dr	4	2000	90	50	Sandy gr	0-88 cl, 88-90 gr. Chemical analysis available.
3	14	82	25			2100	62	10	Gr	Unconsolidated deposits, gr.
15	14	82	25	D	36x36	2110	60		Gr?	Chemical analysis available.
13	17	82	25	D	36x36	2127	15	11		0-13 cl, 13-14 gr, 14-15 rock; continuous pumping possible. Chemical analysis available.
6	18	82	25	D	24x48	2100	22	12	Gr	0-20 cl, 20-22 gr; well can be pumped dry. Chemical analysis available.
6	18	82	25	D	36x36	2100	12.4	4.9	Gr	0-10 cl, 10-12.4 gr; continuous pumping possible. Chemical analysis available.
16	21	82	25	Dr		2105	57		Sd & gr	Chemical analysis available.
16	21	82	25	Dr	4	2146	88	55		0-17 cl, 17-88 gr with sd. Chemical analysis available.
13	22	82	25	D	36x36	2090	9.2	3.8	Gr	Chemical analysis available.
16	22	82	25	D	48x48	2125	14	6	Gr	Chemical analysis available.
5	24	82	25	D	4	2105	78	70	Gr	0-78 gr; continuous pumping possible. Chemical analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
16	24	82	25	Dr	4	2110	100		Sd	0-55 cl, 55-70 gr, 70-100 grey sd. Chemical analysis available.
4	25	82	25	B		2125	128		Sd	Original depth 200 ft., filled with gr. Chemical analysis available.
8	25	82	25		6	2120	183	123	Rock	0-30 cl, 30-70 gr, 70-150 q, 150-160 hard gr, 160-180 blue cl, 180-183 rock; good pumping rate possible. Chemical analysis available.
4	26	82	25	J	4	2145	128		White sd	0-120 blue cl (some rocks), 120-128 sd; good pumping rate possible. Chemical analysis available.
12	26	82	25	D	48x48	2140	36		Gr	0-27 cl, 27-36 gr
16	26	82	25	D		2140	43	40		0-8 cl, 8-43 gr; more water in dry year, less in wet; used to be soft, now hard.
4	30	82	25	D	48x48	2160	50	32		0-8 gr, 8-49 silty sh, 49-50 gr; continuous pumping possible. Chemical analysis available.
16	30	82	25	D	48x48	2155	50		Fine gr	0-22 sd & gr, 22-28 cl, 28-50 sd & gr. Chemical analysis available.
16	30	82	25	D	48x48	2155	16		Sd	0-16 sd & gr
1	32	82	25	D	36x36	2155	57	54	Gr?	Possible to pump well dry. Chemical analysis available.
4	32	82	25	D	48x48	2160	51	49	Coarse gr	0-10 blue cl, 10-51 gr; continuous pumping possible. Chemical analysis available.
16	32	82	25	Dr		2160	99	58	Gr	0-10 sandy cl, 10-50 brown sd & gr, 50-70 ss, 70-100 sd & yellow cl; seams of gr & water. Chemical analysis available.
SE	33	82	25	C			145			0-20 gravelly cl, 20-48 sd & gr, 48-60 loose sd, 60-72 hardpan cl, 72-77 sd & gr, 77-105 blue cl, 105-110 blue cl & ss, 110-130 hardpan, 130-140 sd & cl seams, 140-145 blue cl
9	33	82	25	D	36x36	2160	73	70	Gr	Continuous pumping possible. Chemical analysis available.

Location W. 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
13	34	82	25	D		2150	40	33	Sd	0-40 sd; continuous pumping possible. Chemical analysis available.
1	35	82	25	D	48x48	2145	44	40	Gr	0-12 cl, 12-44 gr; level fluctuates with lake. Chemical analysis available.
1	36	82	25	Dr		2125	120	60	Sd?	Steel casing for 4 ft. Chemical analysis available.
4	1	82	26			1940				0-5 soil profile, 5-10 oxidized brownish till, 10-20 mottled, mainly dark brownish-grey till with some brown streaks, 20-85 dark grey till; samples from 15 ft. hard & dense. Quite dry; no trace of water in hole.
4	1	82	26	B		2010	50			Dry in winter. Chemical analysis available.
12	1	82	26	D	36x36	2025	14.5	7		
10	3	82	26	Spring	48x48	2100	7.3	3.4		Fine gr & sd bottom. Chemical analysis available.
4	10	82	26	D		2160	57	55		0-13 cl, 13-15 gr, 15-18 sd, 18-57 gr. Chemical analysis available.
8	10	82	26	D		2130	11	7.5		0-11 gr; fair supply. Chemical analysis available.
13	10	82	26	D		2150	59	55		0-15 cl, 15-59 gr; steel culvert cribbing. Chemical analysis available.
13	11	82	26	D	48x48	2165	16	8		0-16 cl; continuous pumping possible. Chemical analysis available.
2	13	82	26	Dr		2080	90	F		Chemical analysis available.
5	13	82	26	D	36	2095	20	5	Gr	0-10 cl, 10-20 gr;concrete cribbing. Chemical analysis available.
12	13	82	26	D	48x48	2110	19	15		0-19 dark cl; can't bail out. Chemical analysis available.
5	14	82	26	D		2150	25		Gr?	Possible to pump well dry. Chemical analysis available.
9	16	82	26			2170	60	58		Good supply. Chemical analysis available.
8	22	82	26	D	24	2145	53	52	Gr & sd	Cl above gr. Chemical analysis available.

Location W. 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
9	22	82	26	B	30	2133	46	43	Gr	0-38 cl, 38-46 gr; poor yield. Chemical analysis available.
14	23	82	26	D	48x48	2150	24	21		
4	24	82	26	D	24x24	2140	23	20	Gr	
13	24	82	26	C	4	2155	27	24	Sd	Continuous pumping possible. Chemical analysis available.
	24	82	26				110	10		
4	27	82	26	B	30	2155	51	45		
16	34	82	26	Dr	4	2160	71	61	Sandy gr	Chemical analysis available.
14	35	82	26	D		2175	100	82		0-100 hard black cl (till) stones present
14	35	82	26	Dr	5	2175	130	70		0-20 cl, 20-60 gr, 60-95 sh, 95-105 white ss, 105-130 sh. Chemical analysis available.
16	35	82	26	D		2180	70		Q	Well filled in now.
8	36	82	26	D	48x48	2170	65	62		Chemical analysis available.
NW	31	83	21	R	4	1150	110	90		0-22 sandy cl & silt, 22-90 gr & boulders, 90-110 ss,
	32	82	21		6		56	299		0-20 brown cl, 20-25 grey-brown cl, 25-30 pebbles, 30-38 grey brown cl, 38-40 grey-brown cl & gr, 40-48 gr & sd, 48-48.5 rock, 48-5-55 gr & sd
2	3	82	23	Dr	4	1840	75		Sd	Chemical analysis available.
4	3	83	23	Dr	4	1850	63	20-30		0-3 blue cl, 30-63 q; at 60 ft. hard layer sd & cl. Chemical analysis available.
11	3	83	23	Dr		1860	70			Chemical analysis available.
9	4	83	23	Dr	4	1870	60	48	Pea gr	Continuous pumping possible. Chemical analysis available.
NW	5	83	23	Dr	4	1945	115	15		0-20 cl, 20-40 dry sd & ss, 40-104 ss & cl, 104-106 coarse sd, 106-108 ss, 108-115 gr & water; supply satisfactory.
16	5	83	23	D	30	1925	52	50		Possible to pump dry. Chemical analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
4	6	83	23	C	6	1955	98	22		RCA test hole 65-11 (see Appendix II for lithology)
8	6	83	23	Dr		1945	21	5		
NW	7	83	23	Dr	4 1/2	2025	91	46		0-23 gr & cl, 23-31 coarse sd & cl, 31-58 soft cl & q, 58-64 gr & cl, 64-80 q, 80-90 hard cl & gr, 90-91 water
8	8	83	23	Dr	5	1990	99	30	Sd	0-40 q, 40-58 sd, 58-61 dry gr, 61-99 sd
5	12	83	23	Dr	4	1847	120	80	Fine gr	Mostly sand above seam of gr at bottom. Chemical analysis available.
13	15	83	23	Dr		1948	80-100	F		Freezes in winter. Water flows from flowing well into dug well. Chemical analysis available.
13	15	83	23	D		1948	35			
2	16	83	23	Dr	4	1950	87	35	Sd, pea gr & coal	0-60 q, 60-87 sd, seam of gr at 60. Chemical analysis available.
13	16	83	23	Dr	4	2000	155		Sd	Continuous pumping possible. Chemical analysis available.
SW	18	83	23	Dr		2050	110			0-110 cl, 110-gr, water Chemical analysis available
8	18	83	23	Dr		2025	60		Sandy cl	0-60 cl & sandy strips
NE	18	83	23	R	4	1800	60	35		0-35 sandy cl, 34-40 sd & gr, 40-55 cl, 55-58 sd, gr, water, 58-60 cl
2	19	83	23	B		2030	45		Sd & gr	0-3 gr, 3-42 cl, 42-45 gr; can be pumped dry. Chemical analysis available.
2	19	83	23	B&D		2030	50		Sd & gr	Ss ledges believed at bottom. Chemical analysis available.
9	19	83	23	D	48x48	2075	18	6	Blue cl	Layers of sd & cl to 18 ft. Good supply. Chemical analysis available.

Location West 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
16	19	83	23	D		2090	17		Gr	0-17 gr. Chemical analysis available.
16	19	83	23	Dr		2090	270			0-270 cl, 270 sd; plugged with sand.
5	20	83	23	C	7	2042	40			0-12 till, 12-16 coarse sd & gr, 16-40 silty sh; no water, hole abandoned.
13	24	83	23	Dr	4	1890	52	44	Silt	Possibly total well in cl. Continued pumping possible. Chemical analysis available.
16	26	83	23	Dr	5	1955	127-150	F		Chemical analysis available.
12	27	83	23			2050				Clear water; runs at a good rate. Chemical analysis available.
15	27	83	23	B		2065	15	10		0-2 gr, 2-14 cl, 14-15 gr; some sd at 2 ft. Chemical analysis available. No cribbing and as yet unused; hand augered.
SW	28	83	23	D		2050	10	5		0-10 till, 10 sd.
9	28	83	23	R		2090	35			Chemical analysis available.
9	28	83	23	Dr	5	2090	26		Gr	
NE	28	83	23			2100		F	Gr	0-14 gr
5	29	83	23	C		2120	19	14		Test hole R.C.A. 65-4.
5	29	83	23	C	16	2120	63	14	Gr	0-10 till, 10-23 gr & sd, 23-32 gr, 32-47 sd, 47-55 gr, 55-58 sandy gr, 58-63 dark grey sh. Chemical analysis available. Test hole R.C.A. 65-2
5	29	83	23	D	36x36	2110	8	2		0-8 gr
13	29	83	23		60x60	2120	28	24	Sd & gr	0-8 cl, 8-28 gr. Chemical analysis available.
8	30	83	23	D		2110	15	6	Gr	0-15 gr. Chemical analysis available.
NW	30	83	23	D		2090	30	29		0-17 cl, 17-30 gr
9	31	83	23	D		2100	50			Chemical analysis available.
9	31	83	23	Dr		2100	50	45	Gr	0-5 till, 5-50 gr; can't pump either well dry. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
2	32	83	23	D	36	2120	51	47	Gr	0-1.5 cl, 1.5-20 gr, 20-34 cl, 34-51 gr. Good rate. Chemical analysis available.
4	32	83	23	D	48x48	2115	44	37	Gr	0-15 gr, packed cl, gr. Good pumping rate possible. Chemical analysis available.
12	32	83	23	D	30	2110	43	40	Gr	0-5 yellow cl & r, 5-7 gr; 6 ft. of sandrock at 37 ft. Continuous pumping possible. Chemical analysis available.
8	33	83	23	R	4	2100	53	45	Gr	0-5 cl, 5-53 gr. Chemical analysis available
8	33	83	23	R	4	2100	56	44	Gr	0-6 cl, 6-25 gr, 25-35 sd, 35-56 gr. Chemical analysis available.
8	33	83	23	R	4	2100	55	42	Gr	0-6 cl, 6-25 gr, 25-35 sd, 35-55 gr. Chemical analysis available.
8	33	83	23	R	4	2100	60	45		0-8 sandy brown cl, 8-60 gr (driller's log). Pump tested at 5 gpm for 2 hrs., drawdown 7 ft.; full recovery.
12	34	83	23	D	36x36	2110	50	48	Gr	0-22 cl & sd, 22-50 gr. No noticeable drawdown when pumping. Chemical analysis available.
13	34	83	23	D		2115	38	36	Gr	0-3 cl, 3-8 gr, 8-18 sd, 18-38 gr. Chemical analysis available.
13	34	83	23	R	4	2115	50	36		0-5 cl, some sd; gr. Chemical analysis available.
8	35	83	23	R	4	1980	50	F	Sd & gr	Flows at slow trickle. Chemical analysis available.
1	2	83	24	R	4	2030	115	80	Gr	0-110 cl, 110-115 gr. Pump tested at 5 gpm for 48 hrs. Chemical analysis available.
1	2	83	24	R	4	2030	116	80	Gr	0-10 till, 10-110 blue cl, 110-116 gr. Good yield from both.
1	3	83	24	D	60	2090	46	23	Cl	Chemical analysis available.
9	3	83	24	Dr	4	2110	139	105	Pea gr	0-120 cl, 120-138 hard pan then gr. Continuous pumping possible. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
13	3	83	24	Dr	4	2150	100			Chemical analysis available.
3	4	83	24	D		2150	80	78	Sd & some gr	Casing installed and well deepened to 80 ft. Good yield. Chemical analysis available.
2	5	83	24	D	24	2047	42	40		0-20 cl, 20-42 gr. Good yield. Chemical analysis available.
2	5	83	24	D	48x48	2047	47	46		Chemical analysis available.
1	6	83	24		36	2140	60	59		
4	6	83	24	D	48x48	2150	70	67		Chemical analysis available.
12	7	83	24			2155	45	42		
16	7	83	24		12	2145	12	8		0-6 cl, 6-12 gr. Chemical analysis available.
16	7	83	24		24	2145	7	3		0-6 cl, 6-7 gr. Chemical analysis available.
16	7	83	24		36	2145	13	9		0-6 cl, 6-13 gr. Chemical analysis available.
9	8	83	24	D	36	2005	22	20		Good yield. Chemical analysis available.
8	9	83	24	Dr	4	2150	78	20	Sd & gr	Chemical analysis available.
16	11	83	24	Dr	5	2110	175	135	Fine gr	0-174 blue cl, 174-175 gr; unused, pumps silt & sd.
9	13	83	24	R	5	2100	170	30	Gr	0-170 blue cl, 170 gr. Chemical analysis available.
NW	13	83	24	B			55	49	Ss	0-47 cl, 47-55 ss
NE	13	83	24	Dr			90	7		0-60 cl, 60-90 gr. Sustains 3 igpm.
1	16	83	24	D		2110	29		Gr	0-19 cl, 19-28 gr & sd. Water level fluctuates with lake level. Chemical analysis available.
5	16	83	24	B		2090	35	7		0-24 till, 24-35 gr; well caved in. Chemical analysis available.
1	19	83	24	D		2125	17		Blue cl	0-17 cl, Chemical analysis available.
1	19	83	24	D		2125	17		Blue cl	0-17 cl. Chemical analysis available.
1	19	83	24	D		2125	17	11		
SE	22	83	24	J			200	15		
10	22	83	24	C	6	2125	69	23		Test hole RCA 65-3, see Appendix II for lithologic log. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
1	23	83	24	D	36x36	2080	30	20	Blue cl	0-30 cl. Chemical analysis available.
4	23	83	24	D	36x36	2075	33	27		
4	24	83	24	D	48x48	2090	45			Chemical analysis available.
13	24	83	24	D&B		2100	46	36	Gr	0-46 blue cl, 46 gr. Chemical analysis available.
NW	24	83	24	D		2075	40	20		0-10 gr, 10-15 cl, 15-37 gr, 37-40 cl, 40 sd
2	25	83	24	D	36x36	2100	19	18	Gr	0-19 gr. Chemical analysis available.
2	25	83	24	D	48x48	2100	19	16	Gr	0-8 cl, 8-19 gr. Good yield. Chemical analysis available.
9	35	83	24	D	36x36	2095	32			Abandoned well – no water.
1	36	83	24	D	48x48	2090	40	36	Gr&sd	0-4 cl, 4-40 gr & sd. Good yield. Chemical analysis available.
1	36	83	24	D	48x48	2090	37	36	Gr&sd	0-4 cl, 4-37 gr & sd. Good yield. Level fluctuates with lake level. Chemical analysis available.
16	1	83	25	D		2150	45	42		
3	2	83	25			2140	52		Sd&gr	0-14 cl, 14-52 pea gr. Well is caved in.
9	3	83	25		48x48	2170	54			Well is caved in.
1	4	83	25	D	24	2175	56	54		0-20 cl, 20-70 gr & sd, 70-80 gr, 80-140 q. Chemical analysis available. .Level fluctuates with lake level.
1	5	83	25	D	36x36	2185	71	68		Chemical analysis available.
1	7	83	25	D	36x36	2190	71	70	Gr	Chemical analysis available.
5	8	83	25	D	36x36	2180	77	76	Gr	Chemical analysis available.
8	10	83	25	D		2165	62		Sd	Chemical analysis available.
8	10	83	25	R		2165	67			0-18 cl, 18-100 gr. Well filled in and completed at a depth of 67 feet. Chemical analysis available.
4	12	83	25	D		2155	66	64		Chemical analysis available.
14	12	83	25	Dr	5	2150	75		Gr	Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
1	13	83	25	D	42x42	2150	50	46	Gr	0-15 cl, 15-50 gr. Chemical analysis available.
4	13	83	25	C		2173	175	62		Test hole RCA 65-1. See Appendix II for lithologic log.
4	13	83	25	C		2173	108	57		Test hole RCA 65-1. See Appendix II for lithologic log. Chemical analysis available.
9	13	83	25	D	12	2150	37	32	Sd&gr	Chemical analysis available.
9	13	83	25	D	12	2150	29	27	Sd&gr	Chemical analysis available.
9	13	83	25	C		2150	38		Sd&gr	Chemical analysis available.
4	15	83	25	Dr	4	2175	69			Continuous pumping possible. Chemical analysis available.
7	15	83	25		48x48	2170	67	66		
12	17	83	25			2180	70			Had 2 wells; one filled in, one caved in.
16	17	83	25	D		2175	80	78	Gr	Chemical analysis available.
16	17	83	25	Dr	4	2175	61	53	Gr	0-18 cl, 18-61 gr. Chemical analysis available.
12	18	83	25	Dr	4	2200	90	82	Gr	0-15 cl, 15-90 sandy gr. Chemical analysis available.
4	19	83	25	R	4	2200	78	67	Gr	0-20 cl, 20-78 gr. Good yield. Chemical analysis available.
8	22	83	25	D		2165	60		Gr	0-10 cl, 10-60 gr. Chemical analysis available.
1	23	83	25	Dr	6	2160			Gr	0-9 cl, 9-70 gr, 70+ hard cl. Chemical analysis available.
1	23	83	25	Dr	6	2160			Gr	0-9 cl, 9-70 gr, 70+ blue cl. Chemical analysis available.
5	24	83	25	D	48x48	2155	68		Gr	0-23 cl, 23-68 gr. Water level fluctuates with lake level; 4 in. casing driven in. Chemical analysis available.
3	25	83	25	R		2150	50	41	Pea gr	0-7 cl, 7-50 gr & sd; lake level affects water level, silt a problem with jet pump.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
3	25	83	25	R		2150	50	41	Pea gr & sd	0-7 cl, 7-50 gr & sd; lake level affects water level, silt a problem with jet pump.
16	26	83	25	B	8	2155	30	19	Gr&sd	0-28 blue cl, 28-30 gr. Good yield. Chemical analysis available.
16	26	83	25	B	36	2155	25	15		Chemical analysis available.
2	28	83	25	D	48x48	2190	70	68	Gr	Chemical analysis available.
4	30	83	25	R	4	2200	102	86	Gr	Chemical analysis available.
4	30	83	25	R	4	2200	105	89	Gr	Q at 90 ft. Chemical analysis available.
9	33	83	25	D	48x48	2145	55	31		Continuous pumping possible. Chemical analysis available.
6	34	83	25	D	48x48	2150	33	31	Gr	Chemical analysis available.
12	35	83	25	D	48x48	2140	19	19	Gr	Chemical analysis available.
3	1	83	26	Dr		2180	76	66	Gr	0-14 cl, 14-76 gr
3	1	83	26	R	4	2180	74	67	Gr	0-15 cl, 15-74 gr. Chemical analysis available.
3	2	83	26	D	36x36	2175	81	77		Chemical analysis available.
16	2	83	26	R	4	2200	97	86	Gr	0-97 gr & sd. Chemical analysis available.
8	12	83	26	D	48x48	2200	80	79	Gr	Continuous pumping possible. Chemical analysis available.
1	13	83	26	D	36x36	2200	79	77		
8	23	83	26	D	3 1/2	2190	130	70		0-20 cl, 20-25 sd, 25-90 gr, 90-105 blue cl, 105-106 blue ss, 106-116 white ss, 116-130 sh; open hole finish. Chemical analysis available.
14	23	83	26	Dr	4	2210	160		Fine black silty sd	Silty sd is bedrock. Chemical analysis available.
13	24	83	26	D	36x36	2200	89	82	Sd	Chemical analysis available.
4	25	83	26	D	48x48	2200	80	78	Sd?	Chemical analysis available.
8	35	83	26	D		2210	97	47	Black sd	0-95 blue cl, 95-97 sd. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
13	1	84	23	D	48x48		11	6		Chemical analysis available.
12	2	84	23	D	48x48		47	45	Blue cl	0-200 blue cl, 200 + q. Chemical analysis available.
3	3	84	23			2110				0-200 till; "dry" hole. Chemical analysis available.
4	4	84	23	D	36x36	2150	48	47	Sd	0-20 cl, 20-48 gr, 6iin. ss at 48 ft. Good yield.
5	5	84	23	C		2150	50			Chemical analysis available.
9	5	84	23	Dr		2145	50	41	Gr	0-6 cl & gr, 6-15 fine gr, 15-30 sd & coarse gr, 30-38 fine gr, 38-50 fine sd & gr; pumped at 10 igpm for 3 hrs., no measurable drawdown. Chemical analysis available.
12	5	84	23	R	4		45	42		Chemical analysis available.
1	6	84	23	D	36x36	2145	39	36	Gr	0-12 cl, 12-14 sd, 14-38 gr; continuous pumping possible.
4	8	84	23	D	36x36	2135	32	27		Chemical analysis available.
13	8	84	23	R	4	2125	88	22		0-82 cl (till), 82-88 black silty muck. Chemical analysis available.
4	9	84	23	D	48x48	2115	48	46		0-10 cl, 10-48 gr to ss
13	12	84	23	D	48x48	2100	43	33	Hard blue cl	
5	17	84	23	D	36	2130	22	20	Sandy gr	0-18 cl (till), 18-22 sandy gr; water level varies with climatic conditions
5	18	84	23	D	36x36	2125	30	29		0-7 cl, 7-25 coarse gr, 25-30 fine pea gr; silt trouble in drilled wells. Chemical analysis available.
9	18	84	23	R	4	2135	33	26	Gr&sd	0-13 till, 13-33 gr
9	18	84	23	D	48x48	2135	28	22		0-13 till, 13-28 sandy gr. Chemical analysis available.

Lsd. or 1/4	Locatoon West of 5th Mer. Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
14	18	84	23	D	48x48	2125	23	22		0-21 till, 21-23 sd. Chemical analysis available.
15	18	84	23	R	4	2130	39	27		0-5 cl, 5-39 gr. Chemical analysis available.
9	19	84	23	D	48x48	2140	30	28	Gr	0-12 cl, 12-30 gr. Chemical analysis available.
NE	19	84	23	R	4	1850	40	27		0-5 brown silt & cl, 5-40 gr & sd; well pumped at 6 gpm for one hour with a drawdown of 2 ft. and a recovery to 27 ft.
4	20	84	23	D	36x36	2130	25	23		0-10 cl, 10-25 gr. Chemical analysis available.
4	20	84	23	D	1 1/2	2130	27	23		Chemical analysis available.
4	29	84	23	D	36x36	2130	22	19	Gr	0-6 cl, 6-12 sd, 12-22 gr. Chemical analysis available.
9	1	84	24	R		2145	40		Gr	Chemical analysis available.
9	1	84	24	D		2145			Gr	
15	6	84	24	D	48x48	2130	48	39		Chemical analysis available.
16	7	84	24	B	30	2135	42	22	Brown sd	0-50 cl, 50 sd. Chemical analysis available.
12	8	84	24	D	36x36	2125	40	20	Clayey gr	0-36 cl, 36-40 gr & cl. Chemical analysis available.
10	16	84	24	C	5 1/2	2134	68	19	Ss	0-2.5 soil, 2.5-17 till, 17-59.5 gr, some ss, 59.5-67 sh, 67-68 ss; cased 67 ft. Chemical analysis available. Test hole RCA 65-7, see Appendix II.
11	16	84	24			2145	26	24	Gr	0-3 sd, 3-6 blue cl, 6-25 sd, 25-26 gr. Chemical analysis available.
7	17	84	24	D		2145	33	23		0-32 blue cl, 32-33 yellowish cl. Chemical analysis available.
9	17	84	24	D	48x48	2145	31	27		Chemical analysis available.
13	20	84	24	D	48x48	2150		11		
1	21	84	24	D	3 6x36	2148	30	26		6-30 sd & gr. Chemical analysis available.
8	21	84	24			2150	37	31	Gr	Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
16	22	84	24	D	48x48	2145	24	21		Continuous pumping possible. Chemical analysis available.
2	23	84	24	D	48x48	2140	12	10	Gr	0-10 cl, 10-12 gr. Chemical analysis available.
16	23	84	24	D		2135	20		Gr	Gr at 4 ft. Chemical analysis available.
16	23	›‹	24	D		2135	23		Gr	Chemical analysis available.'
13	24	84	24	D	36x36	2125	10	9	Gr	Good yield. Chemical analysis available.
2	25	84	24	D	36x36	2130	30	25	Gr	0-33 gr. Chemical analysis available.
3	25	84	24	D	36x36	2145	24	22	Sandy gr	0-2.5 cl, 2.5-24 gr. Chemical analysis available.
3	25	84	24	D		2145	24	22	Sandy gr	0-2 cl (till), 2-24 gr. Chemical analysis available.
1	26	84	24	D		2140	11		Gr	Gr at 6 ft. Chemical analysis available.
9	27	84	24	D	48x48	2155	37	35	Gr&sd	Continuous pumping possible. Chemical analysis available.
13	27	84	24	D	48x48	2155	25	23	Coarse gr	Blue cl except for gr; Chemical analysis available.
2	29	84	24	D		2175			Sd	0-18 cl (gumbo), 18-30 sd, 30+ cl; water bitter and very hard.
2	34	84	24	D	48x48	2150	53	51	Sd	0-15 till, 15-24 sd & gr, 24-50 cl, 50-53 sd. Chemical analysis available.
2	34	84	24	D	48x48	2150	53	51	Sd	0-15 till, 15-24 sd & gr, 24-50 cl, 50-53 sd. Chemical analysis available.
5	35	84	24			2145				0-32 cl, 32+ gr; had water at 32 ft., now dry.
4	36	84	24	D		2140	20	16	Sd&gr	Chemical analysis available.
16	36	84	24	D		2135	60	44		0-3 cl, 3-58 sd; hard water.
9	1	84	25	D		2145	46	10		0-46 blue cl. Chemical analysis available.
5	2	84	25	Dr		2145	141	16		Chemical analysis available.
1	4	84	25		24	2150	85			Chemical analysis available.
14	8	84	25	D	30	2210	18			0-18 cl; possible to pump dry, but recovery is rapid. Chemical analysis available.

Lsd. or 1/4	Location West of 5th Mer. Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
14	10	84	25	B	30	2200	82	34 4		0-72 black cl, 72-82 blue sh. Continuous pumping possible. Chemical analysis available.
3	12	84	25	D		2150	32	24	Q	Sd & black cl
8	13	84	25	C	7	2166	140	53	Sh, gr	Test hole RCA 65-6, see Appendix II for lithologic log. Chemical analysis available.
4	15	84	25	D	42x42	2210	3 4	32	Sandy gr	Chemical analysis available.
13	15	84	25	D	48x48	2145	14	12		0-14 cl; possible to pump dry. Chemical analysis available.
3	16	84	25	R	4	2205	47	21	Sd&gr	Good yield. Chemical analysis available.
13	16	84	25	B	24	2200	75	60	Silt	0-75 blue cl; hard water.
1	21	84	25	D	48x48	2250	12	10		Chemical analysis available.
4	11	84	26			2225				0-175 cl
16	2	85	22	D	36x36	2145	17	15		Chemical analysis available.
4	13	85	22	R	4	2125	71	61	Ss	Chemical analysis available.
10	15	85	22	R			121	60	Grey cl	0-83 gr & boulders, 83-118 coarse brown sd, 118-121 grey cl. Chemical analysis available.
16	22	85	22							0-2 cl, 2-30 gr
9	7	85	23	D	48x48	2125	20	12	Sandrock	0-10 cl, 10-20 sd & ss. Chemical analysis available.
3	8	85	23	D	24x24	2120	Spring		Blackish silt	Chemical analysis available.
13	17	85	23	D	48x48	2145	26	23	Hard sd	0-26 cl, 26+ sd. Chemical analysis available.
1	18	85	23	D	48x48	2150	40	30	Sd	0-40 blue cl; good yield. Chemical analysis available.
8	21	85	23	D	48x48	2145	28	25	Sd	0-4 cl, 4-28 sd. Chemical analysis available.
16	21	85	23	D	36x36	2150	34	30	Sd	0-30 very hard sd. Chemical analysis available.
12	22	85	23	D		2150	32	29	Brown sd	0-3 cl, 3-32 packed sd. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
13	22	85	23	D	36x36	2155	30	26	Brown sd	0-4 cl, 4-30 hard packed sd. Chemical analysis available.
11	27	85	23	D		2150	31	28	Grey sd	0-6 cl, 6-16 yellow sd (rocks present), 16-31 grey sd (very hard). Chemical analysis available.
4	29	85	23	D	36x36	2160	41	16		0-40 sandy cl. Chemical analysis available.
16	33	85	23	D	60x60	2150	17	13	Brown sd	Cl above sd. Chemical analysis available.
12	34	85	23	D		2165	36	34		0-3 cl, 3-36 pressed sd
8	1	85	24	D	36x36	2145	18	16	Sd	0-10 cl, 10-18 sd. Chemical analysis available.
8	1	85	24	D	36x36	2145	19	11	Sd	0-10 cl, 10-19 sd. Chemical analysis available.
13	1	85	24	D			13	5		
16	1	85	24	D	36x36	2150	29	19	Cl	0-29 blue cl. Chemical analysis available.
16	1	85	24	D	36x36	2150	20	7	Cl	0-20 blue cl. Chemical analysis available.
1	11	85	24	D	36x36	2175	22	6		Chemical analysis available.
1	5	86	23	D	48x48	2100	42	27	Blue sd	0-36 cl, 36-37 ss, 37-42 blue sd. Chemical analysis available.
9	6	86	23	D	42	2100	18	15	Sd&gr	0-16 cl, 16-18 sandy gr. Chemical analysis available.
16	11	86	24	Dr		2100	49	14		Test hole RCA 65-13, see Appendix II for lithologic log.
16	12	86	24	D	48x48	2080	20	12	Cl	0-20 cl. Chemical analysis available.
12	19	86	24	D	36x36	2150	39	22	Gr	0-8 light cl, 8-38 blue cl, 38-39 gr. Chemical analysis available.
16	23	86	24	Dr	4	2075	52	2	Black sd	0-51 blue cl, 51-52 ss. Chemical analysis available. Stock well 54 ft. deep is flowing.
9	24	86	24	D	36x36	2060	30	0	Light blue cl	0-4 cl, 4-10 brown sd, 10-30 bedrock. Chemical analysis available.
13	24	86	24	R	4	2075	40	4		0-8 gravelly yellow cl (till), 8-32 blue cl, 2 in. rock, black sd below this. Chemical analysis available.

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
2	25	86	24	D	21	2080	51	2		0-51 light blue cl. Chemical analysis available.
4	25	86	24	R	4	2085	35	0		Seam of sd in blue cl; good yield. Chemical analysis available.
1	26	86	24	R	4	2085	40	0	Blue cl	0-40 blue cl; good yield. Chemical analysis available.
3	26	86	24	D	48x48	2090	33	4	Q	0-32 cl, 32-33 ss. Chemical analysis available.
3	26	86	24	D	36x36	2090	38	0	Q	0-36 cl, 36-38 ss. Chemical analysis available.
1	28	86	24	R	4	2100	225	8		Chemical analysis available.
16	21	86	25	D	36x36	2150	20	16		Blue cl, 6 in. of white sd before final blue cl. Chemical analysis available.
16	22	86	25	D	36x36	2160	24	5		Cl then sd. Chemical analysis available.
15	23	86	25	D	24	2150	25	8		Chemical analysis available.
5	25	86	25			2110				0-95 blue cl
4	27	86	25	B	24	2150	28		Sd	0-8 sandy cl, 8-18 blue cl, 4 to 5 in. rock, 18-44 sd. Chemical analysis available.
1	28	86	25			2155	12			0-10 sandy cl, 10+ blue cl; seepage well 12 ft. deep.
4	28	86	25	Dr	4		180	14	Blue cl	0-40 cl, 40-80 sd, 80-180 blue cl. Chemical analysis available.
9	35	86	25	R	4		70	F	Black sd	Blue cl, limestone layer; flowing at 3 gpm. Chemical analysis available.

Lsd. or 1/4	Location West of 6th Mer. Sec.	Tp.	R.	Type of well	Hole diam. (in.)	Estimated surface elev. (ft.)	Well depth (ft.)	Depth to water (ft.)	Aquifer	Lithologic log and remarks
14	33	81	1	B	24	2145	130	18		Chemical analysis available.
16	33	81	1	D & augered	36x36	2135	80	3		0-22 gr, 22-80 blue cl
1	4	82	1	D	36x36	2155	32	29	Gr	Water is very hard
2	6	82	1	B	24	2100	57	7		Chemical analysis available.
16	12	82	1	Dr	30	2195	68	65	Gr	0-18 cl, 18-68 gr. Chemical analysis available.
4	16	82	1	Dr	4	2175	56	50	Gr	0-10 cl (till), 10-56 gr; good yield. Chemical analysis available.
12	16	82	1	D	5	2198	60	59		0-28 cl, 28-36 sd, 36-60 gr. Chemical analysis available.
8	17	82	1	D	30x30	2188	62	61	Gr	0-18 cl, 18-28 gr, 28-58 blue cl, 58-62 gr. Chemical analysis available.
3	18	82	1	D		2145	114	57		0-100 cl, 100-114 q. Chemical analysis available.
9	12	82	2	B	24	2147	65	44	Gr	0-63 blue cl, 63-65 gr. Chemical analysis available.
2	13	82	2							0-37 cl, 37+ gr; high in iron content.
12	13	82	2	B	24	2160	38	36		
9	17	82	2	B	24	2190	78	43		Chemical analysis available.
13	13	84	1	D	36x36	2340	17	14	Q	Cl then q. Chemical analysis available.

Appendix VI. Chemical analyses of well and surface waters

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron Fe (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
14	15	81	24	32	606	264	320	64	52	100	32.0	1.2	1.6	1.5	2.0	2.3	6.4	1.0	7.4
14	15	81	24	51	268	100	180	54	4	150	0.2	0.5	1.3	0.1	4.6	0.0	3.6	0.8	4.4
16	8	81	25	12	924	272	620	316	0	250	0.0	4.0	7.9	0.0	5.0	0.0	12.4	0.5	12.9
15	19	81	25	92	1032	200	260	377	44	250	2.0	2.3	9.4	1.2	5.0	0.1	5.2	10.5	15.7
13	20	81	25	270	1758	226	120	553	58	500	0.0	3.9	13.8	1.6	10.0	0.0	2.4	23.0	25.4
4	26	81	25	100	3210	456	1650	1502	39	330	4.3	7.4	37.6	1.1	6.6	0.3	33.0	12.6	45.6
13	26	81	25	97	3206	440	1550	1614	40	40	13.2	2.75	40.4	1.1	0.8	0.9	31.0	12.2	43.2
5	28	81	25	271	1522	218	390	518	28	525	6.0	15.0	13.0	0.8	10.5	0.4	7.8	16.9	24.7
13	29	81	25	93	2798	478	1050	1236	12	350	7.2	18.0	30.9	0.3	7.0	0.5	21.0	17.7	38.7
8	32	81	25	328	1362	204	440	566	15	520	0.0	2.4	14.2	0.4	10.4	0.0	8.8	16.2	25.0
5	35	81	25	148	2200	282	890	1001	34	160	0.0	10.0+	25.0	1.0	3.2	0.0	17.8	11.4	29.2
15	35	81	25	477	1276	92	190	347	92	500	0.0	7.2	8.7	2.6	10.0	0.0	3.8	17.5	21.3
8	25	81	26	44	1872	144	340	848	11	250	0.0	0.1	21.2	0.3	5.0	0.0	6.8	19.7	26.5
9	25	81	26	32	2328	284	500	1007	7	500	3.3	2.4	25.2	0.2	10.0	0.2	10.0	25.6	35.6
16	8	82	23	24	1386	326	640	445	34	400	22.0	25+	11.1	0.9	8.0	1.6	12.8	8.8	21.6
16	15	82	23	30	3604	680	1880	1724	16	150	14.7	Tr	43.1	0.4	3.0	1.0	37.6	10.0	47.6
12	18	82	23	68	3448	664	1575	1529	65	225	0.0	25+	38.2	1.8	4.5	0.0	31.5	13.0	44.5
1	19	82	23	103	2292	260	915	1086	75	125	0.0	8.7	27.2	2.1	2.5	0.0	18.3	13.5	31.8
13	19	82	23	56	582	116	290	195	0	225	0.0	2.8	4.9	0.0	4.5	0.0	5.8	3.6	9.4
16	21	82	23	23	2500	302	1300	1250	5	190	0.0	0.0	31.3	0.1	3.8	0.0	26.0	9.2	35.2
8	30	82	23	50	840	146	400	335	0	250	0.0	0.6	8.4	0.0	5.0	0.0	8.0	5.4	13.4
14	32	82	23	74	1894	258	955*	940	10	125	0.0	25.5	23.5	0.3	2.5	0.0	21.1	5.2	26.3
14	34	82	23	124	1958	296	980	957	8	65	0.0	4.3	23.9	0.2	1.3	0.0	19.5	5.9	25.4
16	36	82	23	Spring	1426	204	260	401	78	500	0.0	0.8	10.0	2.2	10.0	0.0	5.2	17.0	22.2

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (epm)	Nitrates N (epm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3+ CO_3 (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
13	2	82	24	275	1374	178	560	661	16	100	0.0	0.3	16.5	0.4	2.0	0.0	11.2	7.7	18.9
9	4	82	24	Spring	928	270	545	251	14	340	0.0	4.2	6.2	0.4	6.8	0.0	10.9	2.5	13.4
9	4	82	24	Spring	1398	318	770	498	5	340	0.0	0.2	12.5	0.1	6.8	0.0	15.4	4.0	19.4
16	5	82	24	93	1770	266	885	807	15	225	0.0	10+	20.2	0.4	4.5	0.0	17.7	7.4	25.1
16	7	82	24	80	2628	442	1160	1194	57	225	4.0	4.5	29.9	1.6	4.5	0.3	23.2	13.1	36.3
5	8	82	24	65	1098	250	635	407	30	230	5.9	1.3	10.2	0.8	4.6	0.4	12.7	3.3	16.0
5	9	82	24	53	958	286	530	272	10	325	Tr	29.0	6.8	0.3	6.5	0.0	10.6	3.0	13.6
16	9	82	24	88	594	120	740*	231	2	140	3.5	3.2	5.8	0.1	2.8	0.2	4.8	4.1	8.9
8	10	82	24	54	570	138	370	125	0	275	0.0	0.4	3.1	0.0	5.5	0.0	7.4	1.2	8.6
14	10	82	24	200	1456	228	545	598	25	290	Tr	1.7	15.0	0.7	5.8	0.0	10.9	10.6	21.5
10	13	82	24	87	546	116	255	202	0	175	0.0	0.2	5.1	0.0	3.5	0.0	5.1	3.5	8.6
15	14	82	24	Spring	318	64	245	109	0	140	1.8	0.2	2.7	0.0	2.8	0.1	4.9	0.7	5.6
15	14	82	24	63	432	112	250	144	0	150	0.0	0.0	3.6	0.0	3.0	0.0	5.0	1.6	6.6
SE	15	82	24	62	446	104	310	126	3	250	0.0	6.5	3.2	0.1	5.0	0.0	6.2	2.1	8.3
9	15	82	24	23	674	212	415	134	28	280	19.1	0.2	3.4	0.8	5.6	1.4	8.3	2.9	11.2
9	15	82	24	60	364	72	200	138	0	120	0.0	61.0	3.5	0.0	2.4	0.0	4.0	1.9	5.9
1	16	82	24	160	726	186	290	168	15	350	3.8	8.4	4.2	0.4	7.0	0.3	5.8	6.1	11.9
5	17	82	24		406	176	255	78	8	175	2.0	Tr	2.0	0.2	3.5	0.1	5.1	0.7	5.8
12	17	82	24	83	188	76	60	1	5	125	0.0	29.0	0.0	0.1	2.5	0.0	1.2	1.4	2.6
1	18	82	24	157	472	126	210	108	4	250	1.8	0.4	2.7	0.1	5.0	0.1	4.2	3.7	7.9
14	19	82	24		524	132	330	189	0	150	1.5	0.2	4.7	0.0	3.0	0.1	6.6	1.2	7.8
14	19	82	24	120	568	142	425	190	1	225	0.5	0.0	4.8	0.0	4.5	0.0	8.5	0.8	9.3
14	19	82	24	120	544	166	420	150	0	260	0.0	Tr	3.8	0.0	5.2	0.0	8.5	0.5	9.0
5	20	82	24	135	446	118	300	150	0	150	0.2	0.3	3.8	0.0	3.0	0.0	6.0	0.8	6.8
8	21	82	24	60+	604	368	225	54	0	140	42.0	3.4	1.4	0.0	2.8	3.0	4.5	2.7	7.2
13	21	82	24	120	266	132	175	17	0	200	0.0	0.0	0.4	0.0	4.0	0.0	3.5	0.9	4.4
16	22	82	24	37	1428	160	500	707	0	120	3.2	3.0	17.7	0.0	2.4	0.2	10.0	10.3	20.3

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
16	23	82	24		240	54	110	33	2	175	2.8	4.7	0.8	0.1	3.5	0.2	2.2	2.4	4.6
5	25	82	24	72	820	176	335	268	15	300	0.0	2.6	6.7	0.4	6.0	0.0	6.7	6.4	13.1
4	29	82	24	220	850	130	440	363	8	200	0.0	0.7	9.1	0.2	4.0	0.0	8.8	4.5	13.3
1	30	82	24	26	312	86	130	85	12	110	0.5	9.0	2.1	0.3	2.2	0.0	2.6	2.0	4.6
9	32	82	24	134	600	136	400	182	0	310	0.0	0.0	4.6	0.0	6.2	0.0	8.0	2.8	10.8
11	32	82	24	106	436	86	295	175	2	120	2.0	0.4	4.2	0.1	2.4	0.1	5.9	0.9	6.8
12	33	82	24	92	418	104	250	139	0	140	1.5	1.9	3.5	0.0	2.8	0.1	5.0	1.4	6.4
15	34	82	24	105	750	220	510*	200	0	390	0.0	1.4	5.0	0.0	7.8	0.0	9.4	3.4	12.8
15	35	82	24	38	1230	270	580	427	7	440	0.9	4.4	10.7	0.2	8.8	0.1	11.6	8.2	19.8
15	36	82	24	138	964	196	290	284	24	375	0.8	0.5	7.1	0.7	7.5	0.1	5.8	9.6	15.4
4	2	82	25	266	1226	78	100	377	26	460	0.0	0.4	9.4	0.7	9.2	0.0	2.0	17.3	19.3
9	2	82	25	195	1320	94	135	424	3	520	0.0	6.6	10.6	0.1	10.4	0.0	2.7	18.4	21.1
13	2	82	25	70	926	164	300	307	10	350	1.5	0.5	7.7	0.3	7.0	0.1	6.0	9.1	15.1
13	2	82	25	53	1398	168	625	608	14	350	0.0	2.5	15.2	0.4	7.0	0.0	12.5	10.1	22.6
13	2	82	25	170	1096	100	100	333	46	370	0.0	0.2	8.3	1.3	7.4	0.0	2.0	15.0	17.0
1	3	82	25	164	1592	212	700	657	35	375	1.8	14.8	16.4	1.0	7.5	0.1	14.0	11.0	25.0
12	5	82	25		1094	308	430	419	20	110	3.0	25+	10.5	0.6	2.2	0.2	8.6	4.9	13.5
3	6	82	25	80	2516	316	970	1221	45	110	12.0	32.0	30.5	1.3	2.2	0.9	19.4	15.5	34.9
3	7	82	25		6060	1500	2750*	2607	251	150	150.0	0.0	65.2	7.1	3.0	10.7	65.0	21.0	86.0
8	7	82	25	80	838	388	250	40	24	450	8.0	9.8	1.0	0.7	9.0	0.6	5.0	6.3	11.3
14	7	82	25	32	2536	496	1190	1181	26	100	8.5	1.0	29.5	0.7	2.0	0.6	23.8	9.0	32.8
16	10	82	25	32	506	130	425	168	0	215	1.0	0.1	4.2	0.0	4.3	0.1	8.5	0.1	8.6
14	11	82	25	23	480	142	390	131	0	250	0.2	0.5	3.3	0.0	5.0	0.0	7.8	0.5	8.3
16	12	82	25	90	1396	206	450	633	31	120	0.0	6.4	15.8	0.9	2.4	0.0	9.0	10.1	19.1
15	14	82	25	60	536	176	425*	149	0	265	1.0	1.0	3.7	0.0	5.3	0.1	8.9	0.2	9.1
13	17	82	25	15	724	144	455			50					1.0		9.1		
6	18	82	25	22	1582	220	1120	702	48	215	0.0	0.9	17.6	1.4	4.3	0.0	22.4	0.9	23.3

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
6	18	82	25	12.4	818	238	560	242	8	310	0.0	1.5	6.1	0.2	6.2	0.0	11.2	1.3	12.5
16	21	82	25	88	474	154	315	129	0	225	0.0	1.8	3.2	0.0	4.5	0.0	6.3	1.4	7.7
16	21	82	25	57	436	150	275	127	0	170	0.0	1.5	3.2	0.0	3.4	0.0	5.5	1.1	6.5
13	22	82	25	9.2	186	108	100	14	8	75	4.0	4.2	0.4	0.2	1.5	0.3	2.0	0.4	2.4
16	22	82	25	14	2118	690	1175	453	372	230	100.9	0.3	11.3	10.5	4.6	7.2	23.5	10.1	33.6
5	24	82	25	78	434	138	270	151	0	110	0.0	1.6	3.8	0.0	2.2	0.0	5.4	0.6	6.0
16	24	82	25	100	440	146	270	117	8	175	0.8	0.1	2.9	0.2	3.5	0.1	5.4	1.3	6.7
4	25	82	25	128	1246	294	790	482	0	320	1.5	70.0	12.1	0.0	6.4	0.1	15.8	2.7	18.6
8	25	82	25	183	1074	290	650	402	2	250	0.0	55.0	10.1	0.1	5.0	0.0	13.0	2.2	15.2
4	26	82	25	128	656	150	240	163	0	340	0.0	1.5	4.1	0.0	6.8	0.0	4.8	6.1	10.9
16	26	82	25	42	604	182	350	154	25	225	26.9	2.4	3.9	0.7	4.5	1.9	7.0	4.0	11.0
4	30	82	25	50	380	162	225	82	8	100	17.0	0.1	2.1	0.2	2.0	1.2	4.5	1.0	5.5
16	30	82	25	50	564	208	340	99	18	190	26.1	0.0	2.5	0.5	3.8	1.9	6.8	1.9	8.7
1	32	82	25	56	496	78	320	215	2	110	0.0	1.9	5.4	0.1	2.2	0.0	6.4	1.3	7.7
4	32	82	25	49	312	54	270	97	14	160	0.0	0.4	2.4	0.4	3.2	0.0	5.4	0.6	6.0
16	32	82	25	101	388	78	275	143	0	150	0.0	1.0	3.6	0.0	3.0	0.0	5.5	1.1	6.6
9	33	82	25	73	444	200	255	112	0	150	0.0	2.5	2.8	0.0	3.0	0.0	5.1	0.7	5.8
13	34	82	25	40	2708	320	1500	1291	125	150	0.0	0.0	32.3	3.5	3.0	0.0	30.0	8.8	38.8
1	35	82	25	44	472	210	200	51	38	175	15.6	0.3	1.3	1.1	3.5	1.1	4.0	3.0	7.0
1	36	82	25	120	1116	236	615	502	0	130	0.0	4.8	12.6	0.0	2.6	0.0	12.3	2.9	15.2
4	1	82	26	50	15712	2812	6650	7625	300	615	13.2	40.0	190.6	8.5	12.3	0.9	133.0	82.3	212.3
10	3	82	26	7.3	286	72		103	10	15	0.0	1.5	2.6	0.3	0.3	0.0		3.2	3.2
4	10	82	26	57	458	154	275	143	0	130	0.0	1.6	3.6	0.0	2.6	0.0	5.5	0.7	6.2
8	10	82	26	11	258	80	80	67	0	100	0.0	0.2	1.7	0.0	2.0	0.0	1.6	2.1	3.7
13	11	82	26	16	864	160	515?	394	0	100	0.0	0.4	9.9	0.0	2.0	0.0	5.9	6.0	11.9
2	13	82	26	90	1758	164	370	842	2	240	6.0	0.2	21.1	0.1	4.8	0.4	7.4	19.0	26.4
5	13	82	26	18	3138	604	1740	1406	0	475	2.4	0.0	35.1	0.0	9.5	0.2	34.8	10.0	44.8

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
12	13	82	26	19	2474	486	1360	1096	4	400	2.6	50+	27.4	0.1	8.0	0.2	27.2	8.5	35.7
5	14	82	26	25	1004	366	515	194	91	275	21.0	0.5	4.9	2.6	5.5	1.5	10.3	4.2	14.5
9	16	82	26	60	444	60	325	195	0	125	Tr	0.8	4.9	0.0	2.5	0.0	6.5	0.9	7.4
8	22	82	26	51	4240	186	755	2210	8	360	0.8	1.5	55.3	0.2	7.2	0.1	15.1	47.7	62.8
9	22	82	26	46	1942	480	1180	723	4	475	28.9	3.5	18.1	0.1	9.5	2.1	23.6	6.2	29.8
13	24	82	26	27	996	194	610	386	63	150	0.0	0.1	9.7	1.8	3.0	0.0	12.2	2.3	14.5
16	34	82	26	71	346	104	225	99	0	150	0.0	0.0	2.5	0.0	3.0	0.0	4.5	1.0	5.5
14	35	82	26	130	678	152	380	230	20	200	4.0	0.0	5.8	0.6	4.0	0.3	7.6	3.1	10.7
8	36	82	26	63	296	96	205	78	2	140	0.0	0.3	2.0	0.1	-2.8	0.0	4.1	0.8	4.9
2	3	83	23	75	2016	288	1020	973	11	70	1.4	0.0	24.3	0.3	1.4	0.1	20.4	5.7	26.1
4	3	83	23	63	2038	336	1105	898	20	310	1.5	10+	22.5	0.6	6.2	0.1	22.1	7.3	29.4
11	3	83	23	70	2086	312	1025	1008	20	80	1.9	10+	25.2	0.6	1.6	0.1	20.5	7.0	27.5
9	4	83	23	60	1774	272	980	888	0	70	0.0	10+	22.2	0.0	1.4	0.0	19.6	4.0	23.6
16	5	83	23	52	2786	442	1505	1381	9	40	0.0	1.6	34.5	0.3	0.8	0.0	30.1	5.5	35.6
8	6	83	23	110	1008	250	460	256	40	475	3.4	7.0	6.4	1.1	9.5	0.2	9.2	8.0	17.2
8	6	83	23	20	982	172	260	342	10	310	2.2	5.8	8.6	0.3	6.2	0.2	5.2	10.1	15.3
8	8	83	23	99	488	152	270	134	4	175	3.2	3.5	3.4	0.1	3.5	0.2	5.4	1.8	7.2
5	12	83	23	120	2764	454	1440	1250	14	325	0.0	10+	31.3	0.4	6.5	0.0	28.8	9.4	38.2
13	15	83	23	80-100	1526	370	670	516	15	500	4.0	17.1	12.9	0.4	10.0	0.3	13.4	10.2	23.6
2	16	83	23	87	1418	292	390	433	14	530	0.0	10+	10.8	0.4	10.6	0.0	7.8	14.0	21.8
13	16	83	23	155	1110	240	470	375	9	400	1.9	8.2	9.4	0.3	8.0	0.1	9.4	8.4	17.8
4	18	83	23	110	498	100	225	188	0	160	0.0	7.5	4.7	0.0	3.2	0.0	4.5	3.4	7.9
2	1	83	23	45	702	292	305	172	147	90	15.0	0.3	4.3	4.1	1.8	1.1	6.1	5.2	11.3
2	19	83	23	50	674	198	375	139	34	355	2.5	4.0	3.5	1.0	7.1	0.2	7.5	4.3	11.8
9	19	83	23	17	394	178	215	23	10	260	0.0	2.9	0.6	0.3	5.2	0.0	4.3	1.8	6.1
16	19	83	23	17	360	126	305	65	0	235	1.3	0.3	1.6	0.0	4.7	0.1	6.1	0.3	6.4

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (epm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (ppm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
13	24	83	23	50	2018	268	1280	1007	13	110	0.0	6.2	25.2	0.4	2.2	0.0	25.6	2.2	27.8
16	26	83	23	127	980	124	185*	324	7	350	0.0	1.2	8.1	0.2	7.0	0.0	3.7	11.6	15.3
12	27	83	23	Spring	470	100	315	183	0	150	0.0	0.0	4.6	0.0	3.0	0.0	6.3	1.3	7.6
12	27	83	23	Spring	648	158	390	211	0	260	0.0	0.1	5.3	0.0	5.2	0.0	7.8	2.7	10.5
15	27	83	23	15	446	158	340	142	5	260	1.0	1.3	3.6	0.1	5.2	0.1	6.8	2.2	9.0
9	28	83	23	35	714	200	505	229	0	260	0.0	0.2	5.7	0.0	5.2	0.0	10.1	0.8	10.9
5	29	83	23	26-36	552	122	375	180	0	250	0.0	4.0	4.5	0.0	5.0	0.0	7.5	2.0	9.5
13	29	83	23	26	178	62	125	28	13	90	1.5	0.7	0.7	0.4	1.8	0.1	2.5	0.5	3.0
8	30	83	23	Gr.pit	206	82	75	36	0	100	0.0	0.8	0.9	0.0	2.0	0.0	1.5	1.4	2.9
8	30	83	23	15	346	176	190	63	6	175	11.7	8.0	1.6	0.2	3.5	0.8	3.8	2.3	6.1
9	31	83	23	50	504	166	370	120	4	260	4.3	0.2	3.0	0.1	5.2	0.3	7.4	1.2	8.6
9	31	83	23	50	442	136	225	110	12	175	3.2	0.5	2.8	0.3	3.5	0.2	4.5	2.3	6.8
2	32	83	23	50	598	168	390	149	46	180	10.3	0.3	3.7	1.3	3.6	0.7	7.8	1.5	9.3
4	32	83	23	44	464	160	300	103	10	225	1.8	0.3	2.6	0.3	4.5	0.1	6.0	1.5	7.5
12	32	83	23	41	464	158	295	115	0	225	0.0	0.2	2.9	0.0	4.5	0.0	5.9	1.5	7.4
8	33	83	23	53	480	134	275	145	4	185	0.0	40.0	3.6	0.1	3.7	0.0	5.5	1.9	7.4
8	33	83	23	56	480	106	265	189	0	120	0.0	1.6	4.7	0.0	2.4	0.0	5.3	1.8	7.1
8	33	83	23	55	590	158	370	200	0	200	0.0	1.4	5.0	0.0	4.0	0.0	7.4	1.6	9.0
12	34	83	23	50	388	154	210	102	0	125	0.0	2.4	2.6	0.0	2.5	0.0	4.2	0.9	5.1
13	34	83	23	49	522	160	325	166	39	125	8.0	12.3	4.2	1.1	2.5	0.6	6.5	1.9	8.4
13	34	83	23	50	350	146	210	881	10	125	3.1	35.0	2.0	0.2	2.5	0.2	4.2	0.7	4.9
8	35	83	23	50	938	278	500	369	7	130	0.0	3.7	9.2	0.2	2.6	0.0	10.0	2.0	12.0
1	2	83	24	115	592	164	300	211	0	150	0.0	2.9	5.3	0.0	3.0	0.0	6.0	2.3	8.3
1	2	83	24	116	494	156	315	38	0	425	0.0	0.3	0.9	0.0	8.5	0.0	6.3	3.1	9.4
1	3	83	24	45	766	210	315	237	3	275	6.0	2.0	5.9	0.1	5.5	0.4	6.3	5.6	11.9
9	3	83	24	139	428	94	275	161	0	135	0.0	6.5	4.0	0.0	2.7	i	5.5	1.2	6.7
13	3	83	24	92	398	132	235	125	0	125	0.0	Tr	3.1	0.0	2.5	0.0	4.7	0.9	5.6

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
2	5	83	24	46	518	132	315	198	0	110	2.0	0.7	5.0	0.0	2.2	0.1	6.3	1.0	7.3
2	5	83	24	42	500	142	300	225	0	150	Tr	0.2	5.6	0.0	3.0	0.0	6.0	2.6	8.6
4	6	83	24	70	430	120	290	138	0	150	1.5	3.8	3.5	0.0	3.0	0.1	5.8	0.8	6.6
16	7	83	24	12	360	114	260	110	1	135	0.0	0.5	2.8	0.0	2.7	0.0	5.2	0.3	5.5
16	7	83	24	7	276	60	175	92	0	125	0.0	0.6	2.2	0.0	2.5	0.0	3.4	1.3	4.7
16	7	83	24	13	304	86	175	83	8	125	0.1	1.4	2.1	0.2	2.5	0.0	3.4	1.4	4.8
9	8	83	24	21	570	160	325	184	0	180	3.0	0.5	4.6	0.0	3.6	0.2	6.5	1.9	8.4
8	9	83	24	78	600	224	355	158	0	225	0.0	Tr	4.0	0.0	4.5	0.0	7.1	1.4	8.5
9	13	83	24	170	1138	272	655	417	0	350	2.3	4.4	10.4	0.0	7.0	0.2	13.1	4.5	17.6
1	16	83	24	29	548	172	350	161	0	215	Tr	2.1	4.0	0.0	4.3	0.0	7.0	1.3	8.3
5	16	83	24	21	1984	422	1190	859	8	260	0.0	0.4	21.5	0.2	5.2	0.0	23.8	3.1	26.9
5	16	83	24	Lake	534	112	280	214	0	150	0.6	0.1	5.4	0.0	3.0	0.0	5.6	2.8	8.4
1	19	83	24	17	550	122	360	176	0	250	3.4	0.3	4.4	0.0	5.0	0.2	7.2	2.4	9.6
1	19	83	24	17	620	188	400	185	0	240	1.7	0.4	4.6	0.0	4.8	0.1	8.0	1.5	9.5
10	22	83	24	55-69	1478	294	940	619	2	285	0.0	Tr	15.5	0.1	5.7	0.0	16.8	4.5	21.3
1	23	83	24	30	2142	604	1350	618	138	375	68.4	1.9	15.5	3.9	7.5	4.9	27.0	4.8	31.8
4	24	83	24	45	2352	686	1290	708	168	160	90.0	6.5	17.7	4.7	3.2	6.4	25.8	6.2	32.0
13	24	83	24	46	2134	376	1035	997	11	175	5.2	12.8	24.9	0.3	3.5	0.4	20.7	8.4	29.1
2	25	83	24	19	496	172	270	151	4	100	5.7	1.8	3.8	0.1	2.0	0.4	5.4	0.9	6.3
2	25	83	24	17	336	108	180	71	32	110	Tr	1.8	1.8	0.9	2.2	0.0	3.6	1.3	4.9
1	36	83	24	40	442	154	270	104	14	175	4.1	0.2	2.6	0.4	3.5	0.3	5.4	1.4	6.8
1	36	83	24	37	694	140	410	271	25	100	5.0	8.0	6.8	0.7	2.0	0.4	8.2	1.7	9.9
16	36	83	24	45-50	452	100	240	135	6	183	0.0	0.1	3.4	0.2	3.7	0.0	4.8	2.5	7.3
16	36	83	24	85-90	466	118	260	127	4	207	0.0	0.1	3.2	0.1	4.1	0.0	5.2	2.2	7.4
16	36	83	24	44	300	100	225	70	5	150	2.9	0.8	1.8	0.1	3.0	0.2	4.5	0.6	5.1
16	1	83	25	45	378	100	175	118	0	150	0.0	15.0	3.0	0.0	3.0	0.0	3.5	2.5	6.0
1	4	83	25	56	440	106	280	144	0	175	2.0	0.2	3.6	0.0	3.5	0.1	5.6	1.6	7.2

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
1	5	83	25	70	236	76	160	55	0	130	0.0	Tr	1.4	0.0	2.6	0.0	3.2	0.8	4.0
1	7	83	25	71	560	140	360	194	0	185	0.8	Tr	4.9	0.0	3.7	0.1	7.2	1.5	8.7
5	8	83	25	77	564	150	360	198	0	165	0.0	19.0	5.0	0.0	3.3	0.0	7.2	1.1	8.3
8	10	83	25	62	528	140	325	182	5	145	7.7	0.3	4.6	0.1	2.9	0.6	6.5	1.7	8.2
8	10	83	25	67	696	176	350	216	0	150	1.7	4.4	5.4	0.0	3.0	0.1	7.0	1.5	8.5
4	12	83	25	66	486	90	285	196	2	150	0.0	0.4	4.9	0.1	3.0	0.0	6.9	1.1	8.0
14	12	83	25	75	408	90	275	137	0	150	2.0	6.5	3.4	0.0	3.0	0.1	5.5	1.0	6.5
1	13	83	25	50	474	134	250	161	1	125	3.0	0.2	4.0	0.0	2.5	0.2	5.0	1.7	6.7
4	13	83	25	100-110	448	74	280	174	0	160	0.0	4.5	4.4	0.0	3.2	0.0	5.6	2.0	7.6
9	13	83	25	29	388	112	250	118	0	150	0.2	0.4	3.0	0.0	3.0	0.0	5.0	1.0	6.0
9	13	83	25	38	396	44	215	160	0	125	3.0	0.4	4.0	0.0	2.5	0.2	4.3	2.4	6.7
9	13	83	25	36	516	140	360	164	4	140	7.6	1.2	4.1	0.1	2.8	0.5	7.2	0.3	7.5
16	17	83	25	80	418	126	300	132	0	140	1.5	Tr	3.3	0.0	2.8	0.1	6.0	0.2	6.2
16	17	83	25	61	318	80	210	97	0	140	0.8	0.5	2.4	0.0	2.8	0.1	4.2	1.1	5.3
12	18	33	25	90	644	90	280	294	5	100	0.0	0.1	7.4	0.1	2.0	0.0	5.6	3.9	9.6
4	19	83	25	78	642	272	400	179	0	175	1.5	2.6	4.5	0.0	3.5	0.1	8.0	0.1	8.1
8	22	83	25	60	492	220	250	88	30	150	9.3	2.4	2.2	0.8	3.0	0.6	5.0	1.6	6.6
1	23	83	25	70+	428	94	320	176	0	100	3.3	0.4	4.4	0.0	2.0	0.2	6.4	0.2	6.6
1	23	83	25	70+	320	112	210	85	8	110	8.7	0.2	2.1	0.2	2.2	0.6	4.2	0.9	5.1
5	24	83	25	68	520	132	315	182	10	100	5.9	0.2	4.6	0.3	2.0	0.4	6.3	1.0	7.3
16	26	83	25	30	720	166	450	266	0	230	0.0	2.2	6.7	0.0	4.6	0.0	9.0	2.3	11.3
16	26	83	25	24	2798	556	1580	1523	38	360	0.0	2.1	38.1	1.1	7.2	0.0	31.6	14.8	46.4
4	30	83	25	105	236	94	175	50	0	120	0.2	1.4	1.3	0.0	2.4	0.0	3.5	0.2	3.7
4	30	83	25	102	296	118	210	70	0	125	1.5	Tr	1.8	0.0	2.5	0.1	4.2	0.2	4.4
9	33	83	25	54	1108	252	680	460	0	200	0.0	3.9	11.5	0.0	4.0	0.0	13.6	1.9	15.5
6	34	83	25	31	644	72	440	285	0	200	0.4	0.8	7.1	0.0	4.0	0.0	8.8	2.3	11.1
12	35	83	25	18	504	84	370	190	0	215	1.0	0.2	4.8	0.0	4.3	0.0	7.4	1.7	9.1

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
3	1	83	26	74	300	102	190	73	0	150	0.0	0.0	1.8	0.0	3.0	0.0	3.8	1.0	4.8
3	2	83	26	80	2004	462	1125	823	20	325	1.8	3.5	20.6	0.6	6.5	0.1	22.5	5.3	27.8
16	2	83	26	97	480	86	300	181	0	170	0.0	0.2	4.5	0.0	3.4	0.0	6.0	1.9	7.9
8	12	83	26	79	362	34	360*	163	0	130	0.1	Tr	4.1	0.0	2.6	0.0	6.6	0.1	6.7
8	23	83	26	130	318	94	255	87	10	130	3.5	0.1	2.2	0.3	2.6	0.2	5.1	0.2	5.3
14	23	83	26	160	748	130	170	269	0	230	0.0	0.6	6.7	0.0	4.6	0.0	3.4	7.9	11.3
13	24	83	26	87	572	140	355	217	0	150	0.0	0.0	5.4	0.0	3.0	0.0	7.1	1.3	8.4
4	25	83	26	80	274	76	135	106	0	40	0.0	0.0	2.7	0.0	0.8	0.0	2.7	0.8	3.5
13	1	84	23	8	130	42	100	30	2	80	Tr	0.2	0.8	0.1	1.6	0.0	2.0	0.5	2.
12	2	84	23	46	1266	174	805	577	0	280	0.0	4.5	14.4	0.0	5.6	0.0	16.1	3.9	20.0
3	3	84	23	Spring	356	70	215	126	0	150	0.0	0.1	3.2	0.0	3.0	0.0	4.3	1.9	6.2
3	3	84	23	Spring	234	96	160	37	0	120	0.0	0.0	0.9	0.0	2.3	0.0	3.2	0.1	3.3
4	4	84	23	48	256	80	175	52	10	125	3.4	0.5	1.3	0.3	2.5	0.2	3.5	0.8	4.3
5	5	84	23	50?	854	138	365	382	0	150	0.0	0.5	9.6	0.0	3.0	0.0	7.3	5.3	12.6
9	5	84	23	54	596	202	310	195	0	150	0.0	0.4	4.9	0.0	3.0	0.0	6.2	1.7	7.9
12	5	84	23	45	478	146	315	88	8	220	1.9	0.0	2.2	0.2	4.4	0.1	6.3	0.6	6.9
1	6	84	23	39	508	194	305	134	8	150	2.0	0.3	3.4	0.2	3.0	0.1	6.1	0.6	6.7
4	8	84	23	31	506	74	320	220	0	150	0.0	0.3	5.5	0.0	3.0	0.0	6.4	2.1	8.5
13	8	84	23	88	586	70	245	262	0	140	0.0	0.4	6.6	0.0	2.8	0.0	4.9	4.5	9.4
5	17	84	23	22	396	70	270	135	8	170	2.2	0.1	3.4	0.2	3.4	0.2	5.4	1.8	7.2
5	18	84	23	30	318	106	240	57	0	225	Tr	0.8	1.4	0.0	4.5	0.0	4.8	1.1	5.9
9	18	84	23	28	666	88	190	266	0	200	0.0	0.1	6.7	0.0	4.0	0.0	3.8	6.9	10.7
14	18	84	23	23	582	144	220	175	8	160	18.0	3.2	4.4	0.2	3.2	1.3	4.4	4.7	9.1
15	18	84	23	39	342	66	80	131	2	80	0.0	11.4	3.3	0.1	1.6	0.0	1.6	3.4	5.0
9	19	84	23	30	150	45	75	19	10	95	0.0	0.2	0.5	0.3	1.9	0.0	1.5	1.2	2.7
4	20	84	23	25	264	48	120	94	0	100	0.0	0.1	2.4	0.0	2.0	0.0	2.4	2.0	4.4

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of c[illegible] anions
4	20	84	23	27	182	84	145	15	0	150	0.0	0.0	0.4	0.0	3.0	0.0	2.9	0.5	3.4
4	29	84	23	22	710	178	230	263	0	180	0.0	0.4	6.6	0.0	3.6	0.0	7.2	3.0	10.2
9	1	84	24	40	510	124	260	180	12	125	2.5	1.0	4.5	0.3	2.5	0.2	5.2	2.3	7.5
3	2	84	24	35	416	130	280	85	2	235	0.0	0.0	2.1	0.1	4.7	0.0	4.6	2.3	6.9
15	6	84	24	47	3794	632	1950	1784	28	290	3.3	8.3	44.6	0.8	5.8	0.2	39.0	12.4	51.4
16	7	84	24	40	3484	522	1740	1756	4	100	0.0	2.5	43.9	0.1	2.0	0.0	34.8	11.2	46.0
12	8	84	24	38	3898	606	2025	1866	8	325	0.0	6.5	46.7	0.2	6.5	0.0	40.5	12.9	53.4
10	16	84	24	34-54	912	124	540	436	0	150	0.0	4.2	10.9	0.0	3.0	0.0	10.8	3.1	13.9
11	16	84	24	26	2130	416	1375	945	3	350	13.9	1.3	23.6	0.1	7.0	1.0	27.5	4.2	31.7
7	17	84	24	33	2418	432	1480	1197	0	150	0.0	0.0	29.9	0.0	3.0	0.0	29.6	3.3	32.9
9	17	84	24	28	2536	430	1520	1183	0	300	5.0	1.8	29.6	0.0	6.0	0.4	30.4	5.6	36.0
1	21	84	24	29	490	92	370	156	0	240	0.4	0.4	3.9	0.0	4.8	0.0	7.4	1.3	8.7
8	21	84	24	37	404	64	140	168	0	100	0.0	21.5	4.2	0.0	2.0	0.0	2.8	3.4	6.2
16	22	84	24	23	444	178	310	89	10	200	4.7	0.7	2.2	0.3	4.0	0.3	6.2	0.6	6.8
2	23	84	24	12	360	136	235	89	0	170	0.0	0.5	2.2	0.0	3.4	0.0	4.7	0.9	5.6
16	23	84	24	20	392	188	245	46	30	160	11.3	Tr	1.2	0.8	3.2	0.8	4.9	1.1	6.0
16	23	84	24	23	322	86	210	76	18	160	3.3	0.5	1.9	0.5	3.2	0.2	4.2	1.6	5.8
13	24	84	24	10	242	112	130	40	2	100	4.6	1.5	1.0	0.1	2.0	0.3	2.6	0.8	3.4
2	25	84	24	28	292	48	190	109	8	100	18.0	0.0	2.7	0.2	2.0	1.3	3.8	2.4	6.2
3	25	84	24	24	344	56	135	124	4	120	1.8	0.0	3.1	0.1	2.4	0.1	2.7	3.0	5.7
3	25	84	24	24	226	86	140	22	23	90	10.2	0.0	0.6	0.6	1.8	0.7	2.8	0.9	3.7
12	25	84	24	Creek	360	140	170	96	0	125	0.2	1.0	2.4	0.0	2.5	0.0	3.4	1.5	4.9
1	26	84	24	11	286	88	90	37	8	160	0.0	0.1	0.9	0.2	3.2	0.0	1.8	2.5	4.3
9	27	84	24	35	292	106	250	58	2	182	1.9	0.2	1.5	0.1	3.6	0.1	5.0	0.3	5.3
13	27	84	24	24	808	160	550	335	4	160	0.0	0.8	8.4	0.1	3.2	0.0	11.0	0.7	11.7

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 + CO_3 (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
2	34	84	24	53	932	268	600	287	43	250	3.3	0.0	7.2	1.2	5.0	0.1	12.0	1.5	13.5
2	34	84	24	53	700	166	488	234	0	275	0.0	2.4	5.9	0.0	5.5	0.0	9.8	1.6	11.4
4	36	84	24	20	430	208	290	54	0	225	0.0	0.1	1.4	0.0	4.5	0.0	5.8	0.1	5.9
9	1	84	25	46	2162	384	1070	1009	15	200	1.2	1.7	25.2	0.4	4.0	0.1	21.4	8.3	29.7
5	2	842	25	141	1350	290	750	533	0	340	3.8	6.0	13.3	0.0	6.8	0.1	15.0	5.2	20.2
1	4	84	25	85	348	96	125	44	1	225	0.0	8.2	1.1	0.0	4.5	0.0	2.5	3.1	5.6
14	8	84	25	18	1124	220	720	514	10	110	5.2	0.0	12.9	0.3	2.2	0.4	14.4	1.4	15.8
14	10	84	25	82	1678	284	955	885	4	100	0.0	0.1	22.1	0.1	2.0	0.0	19.1	5.1	24.2
8	13	84	25	140	1410	298	920	575	6	300	0.0	Tr	14.4	0.2	6.0	0.0	18.4	2.2	20.6
4	15	84	25	34	2616	486	1470	1285	2	150	1.9	0.0	32.1	0.1	3.0	0.1	29.4	5.9	35.3
13	15	84	25	14	762	210	450	321	1	200	0.0	0.0	8.0	0.0	4.0	0.0	9.0	3.0	12.0
3	16	84	25	47	534	104	370	222	4	130	0.0	0.0	5.6	0.1	2.6	0.0	7.4	0.9	8.3
1	21	84	25	10	724	144	455	321	0	100	0.0	0.4?	8.0	0.0	2.0	0.0	9.1	0.9	10.0
16	2	85	22	14	386	148	240	82	6	200	0.0	2.8	2.1	0.2	4.0	0.0	4.8	1.5	6.3
4	13	85	22	71	232	88	195	41	0	170	0.0	4.6	1.0	0.0	3.4	0.0	3.9	0.5	4.4
10	15	85	22	121	130	58	50	10	0	75	0.5	0.5	0.3	0.0	1.5	0.0	1.0	0.8	1.8
9	7	85	23	20	1946	404	1260*	901	2	250	0.0	0.0	22.5	0.1	5.0	0.0	24.0	3.5	27.5
3	8	85	23	Spring	710	74	300	333	0	140	2.0	0.1	8.3	0.0	2.8	0.1	6.0	5.2	11.2
13	17	85	23	26	286	132	265	37	0	230	0.0	0.0	0.9	0.0	4.6	0.0	5.3	0.2	5.5
1	18	85	23	40	2024	414	925	926	0	180	5.8	0.3	23.2	0.0	3.6	0.4	18.5	8.7	27.2
8	21	85	23	28	164	102	95	11	2	70	4.1	0.2	0.3	0.1	1.4	0.3	1.9	0.2	2.1
16	21	85	23	33	138	30	75	45	0	60	0.0	0.1	1.1	0.0	1.2	0.0	1.5	0.8	2.3
12	22	85	23	32	230	100	175	32	0	150	0.6	0.0	0.8	0.0	3.0	0.0	3.5	0.3	3.8
13	22	85	23	30	308	104	178	48	35	80	14.0	1.0	1.2	1.0	1.6	1.0	3.5	1.3	4.8
11	27	85	23	30	310	144	225	34	5	220	0.0	0.1	0.9	0.1	4.4	0.0	4.5	0.9	5.4
4	29	85	23	40	298	136	235	25	15	210	2.8	0.0	0.6	0.4	4.2	0.2	4.7	0.7	5.4

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (ppm)	Nitrates N (ppm)	Iron (ppm)	Anions SO_4 (epm)	Anions Cl (epm)	Anions HCO_3 $+CO_3$ (epm)	Anions NO_3 (epm)	Cations Ca +Mg (epm)	Cations Na+K (epm)	Sum of anions
16	33	85	23	15	614	116	280	235	2	200	0.5	0.1	5.9	0.1	4.0	0.0	5.6	4.4	10.0
8	1	85	24	19	440	126	265	136	12	150	0.0	0.1	3.4	0.3	3.0	0.0	5.3	1.4	6.7
8	1	85	24	18	348	100	260	122	0	110	0.0	0.0	3.1	0.0	2.2	0.0	5.2	0.1	5.3
13	1	85	24	10	1412	210	1000	631	15	245	0.0	3.1	15.8	0.4	4.9	0.0	20.0	1.1	21.1
16	1	85	24	29	2176	308	1280	1102	0	200	1.8	3.5	27.6	0.0	4.0	0.1	25.6	6.1	31.7
16	1	85	24	20	2566	378	1540	1309	0	200	0.8	1.0	32.7	0.0	4.0	0.0	30.8	5.9	36.7
1	11	85	24	20	1392	264	975	561	0	375	0.0	4.2	14.0	0.0	7.5	0.0	19.5	2.0	21.5
1	5	86	23	42	1524	176	450	710	2	270	1.4	0.1	17.8	0.1	5.4	0.1	9.0	14.4	23.4
9	6	86	23	18	986	180	485	376	69	150	0.0	0.5	9.4	1.9	3.0	0.0	9.7	4.6	14.3
16	12	86	24	20	4028	260	560	1058	1074	290	12.0	0.3	26.5	30.3	5.8	0.9	11.2	52.3	63.5
12	19	86	24	39	1230	236	555	569	0	150	0.0	0.8	14.2	0.0	3.0	0.0	11.1	6.1	17.2
16	23	86	24	52	2676	180	70	941	100	660	4.2	0.4	23.5	2.8	13.2	0.3	1.4	38.4	39.8
9	24	86	24	30	2296	198	220	418	210	1070	6.5	1.6	10.5	5.9	21.4	0.5	4.4	33.9	38.3
13	24	86	24	40	2870	144	95	1044	100	720	2.4	0.6	26.1	2.8	14.4	0.2	1.9	41.6	43.5
2	25	86	24	51	3664	472	930	1547	175	450	7.9	60.0?	38.7	4.9	9.0	0.6	18.6	34.6	53.2
4	25	86	24	35	2600	184	170	1000	130	500	2.0	10.0	25.0	3.7	10.0	0.1	3.4	35.4	38.8
1	26	86	24	40	2656	212	190	1039	148	450	0.8	6.5	26.0	4.2	9.0	0.0	3.8	35.4	39.2
3	26	86	24	33	2906	220	130	1185	110	450	5.0	0.3	29.6	3.1	9.0	0.4	2.6	39.5	42.1
3	26	86	24	38	2826	124	95	1068	136	600	4.0	0.8	26.7	3.8	12.0	0.3	1.9	40.9	42.8
1	28	86	24	225	3956	262	325	1559	298	600	7.4	30.0	39.0	8.4	12.0	0.5	6.5	53.4	59.9
16	21	86	25	20	4292	688	2300	2153	20	150	9.8	0.5	53.8	0.6	3.0	0.7	46.0	12.1	58.1
16	22	86	25	24?	880	122	300	368	0	250	1.8	1.1	9.2	0.0	5.0	0.1	6.0	8.3	14.3
15	23	86	25	23	970	208	550	306	50	300	0.8	1.0	7.7	1.4	6.0	0.1	11.0	4.2	15.2
4	27	86	25	28	4394	674	2380	2215	36	170	17.0	0.0	55.4	1.0	3.4	1.2	47.6	13.4	61.0
4	28	86	25	180	1410	170	310	621	2	320	0.0	0.1	15.5	0.1	6.4	0.0	6.2	15.8	22.0
9	35	86	25	70	4638	398	440	1972	61	880	0.4	0.7	49.3	1.7	17.6	0.0	8.8	59.8	68.6

Location West of 6th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Depth of well (feet)	Total solids (ppm)	Ignition loss (ppm)	Hardness $CaCO_3$ (ppm)	Sulfates SO_3 (ppm)	Chlorides Cl (ppm)	Alkalinity $CaCO_3$ (epm)	Nitrates N (epm)	Iron (epm)	Anions SO_4 (epm)	Cl (epm)	HCO_3 $+CO_3$ (epm)	NO_3 (epm)	Cations Ca +Mg (epm)	Na+K (epm)	Sum of anions
14	33	81	1	130	2180	760	1535	1184	0	170	5.3	0.0	29.6	0.0	3.4	0.4	30.7	2.7	33.4
11	35	81	1	Spring	282	128	200	93	0	115	Tr	0.0	2.3	0.0	2.3	0.0	4.0	0.6	4.6
2	6	82	1	55	3510	116	1535	1633	0	180	0.0	1.3	40.8	0.0	3.6	0.0	30.7	13.7	44.4
16	12	82	1	68	312	92	220	94	0	150	0.0	0.1	2.4	0.0	3.0	0.0	4.4	1.0	5.4
4	16	82	1	56	916	179	585*	438	5	100	0.0	0.0	0.0	11.0	0.1	2.0	11.7	1.4	13.1
12	16	82	1	60	648	58	210	286	3	170	0.0	0.0	7.2	0.1	3.4	0.0	4.2	6.5	10.7
8	17	82	1	62	436	90	300	171	0	130	2.3	0.2	4.3	0.0	2.6	0.2	6.0	1.1	7.1
3	18	82	1	114	3014	340	1555	1539	10	120	5.1	25.0	38.5	0.3	2.4	0.4	31.1	10.5	41.6
9	12	82	2	64	3034	394	1630	1534	15	150	0.0	0.1	38.4	0.4	3.0	0.0	32.6	9.2	41.8
9	17	82	2	78	3204	410	1650	1632	24	100	0.8	9.8	40.8	0.7	2.0	0.0	33.0	10.5	43.5
13	13	84	1	15	2112	694	1225	633	110	250	40.0	0.1	15.8	3.1	5.0	2.9	24.5	2.8	26.8

*Hardness value questionable (ie. value of Ca+Mg in epm calculated from hardness is different from experimentally determined value of Ca+Mg).

Enclosure # 1 Surficial geology, Grimshaw-Cardinal Lake area.

LEGEND

CENOZOIC

Recent

- Eroded slopes, colluvium, slump and slide material, on steep slopes; involves mainly glacial materials.
- River alluvium and terrace deposits; sand, silt, gravel.
- Lacustrine & alluvial flood plain deposits; sand, silt, clay, muck.
- Slump and slide debris, and slides; on relatively gentle slopes; involves mainly glacial materials.
- Alluvial fan; mainly silt
- Muskeg

Pleistocene

Glacio-lacustrine

- Clay, silt, varved clay and silt, minor sand. Includes Recent lacustrine and alluvium in places.
- Thin (to absent) lacustrine clay and silt overlying till. Includes Recent lacustrine and alluvium in places.
- Lacustrine shoreline; discontinuous sandy or gravelly beach ridge at edge; poorly developed, minor strand lines on till.
- Eroded till plain, fluted ground moraine exposed. Lacustrine sediment generally lacking. Lag gravels present locally at southern end. Forms southern arm of glacial Lake Cardinal.
- Beach ridge; sand and gravel; sand and silt.
- Minor strand line; lineation caused by glacial lake recession.

Glaciofluvial

- Sand and silt, some gravel; moderately to strongly hummocky topography.
- Kame; mainly sand; topographically high
- Spillway or meltwater channel; often veneered with Recent lacustrine silt and clay.

Glacial

- Thin till cover over bedrock upland. Surface expression controlled by bedrock topography.
- Ground moraine; till; till with interlenses of silt and sand and thin surface sand and gravel. Includes one small area of washboard moraine. Till containing large amounts of well rounded pebbles derived from the "Grimshaw gravels," local pockets of sand, silt, gravel.
- Thin till cover over gravel ridges of drumlinoid form. Includes drumlinoid tails of till with little or no underlying gravel.
- Washboard moraine-discontinuous linear ridge composed mainly of till.
- Sinuous, discontinuous, ridges of till.
- Flutings, straight parallel ridges and grooves in till.
- Glacial lineament, less well pronounced than flutings.
- Drumlin. Direction of ice movement indicated by arrow.

Pleistocene and/or older

- + Pit or outcrop exposing "Grimshaw gravels;" gravel, sand.

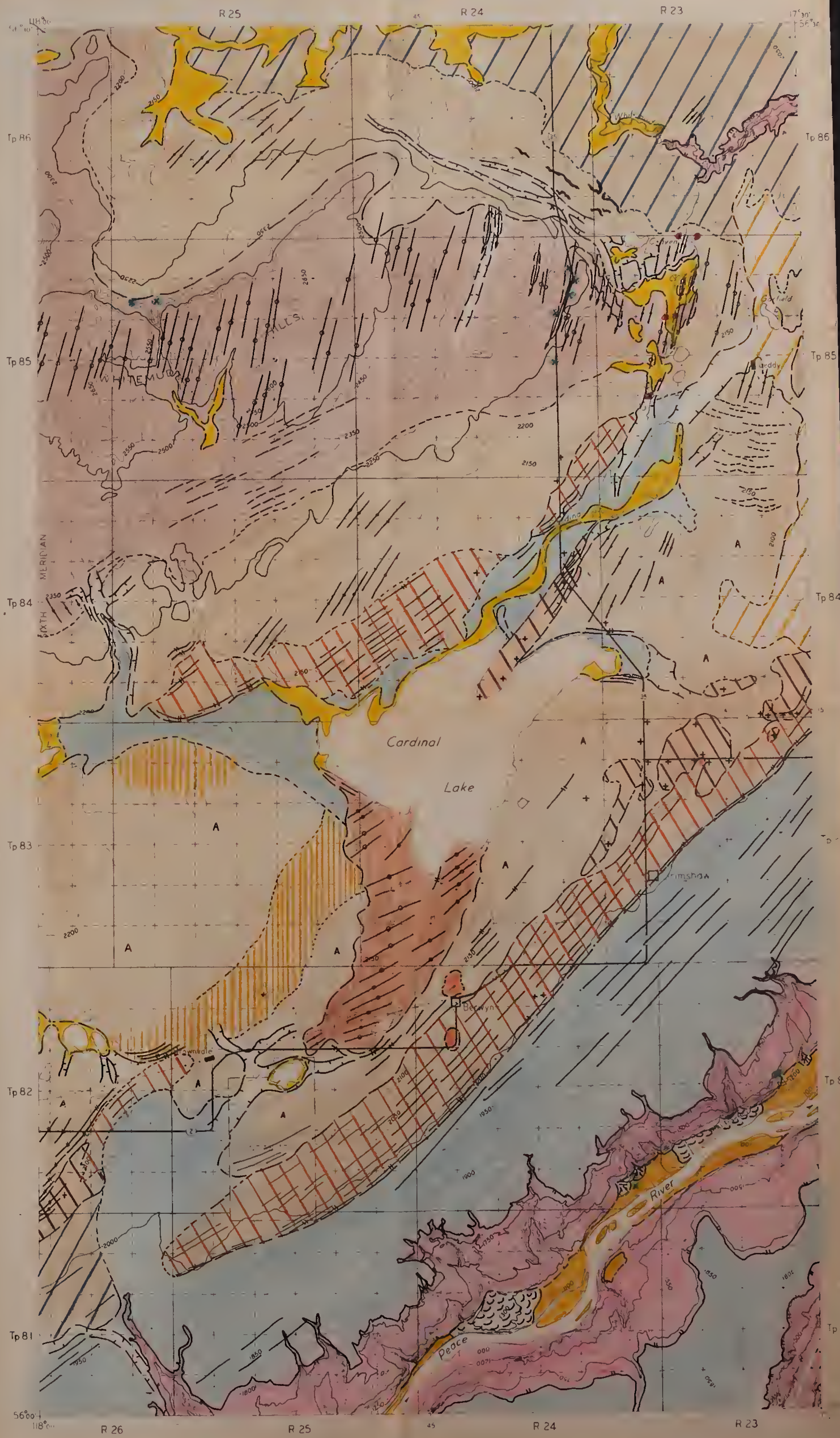
MESOZOIC

Cretaceous

- Bedrock outcrop. Kaskapau Formation (shale)
- Bedrock outcrop. Dunvegan Formation (sandstone & silty shale)
- Bedrock outcrop. Shaftesbury Formation (shale)

OTHER SYMBOLS

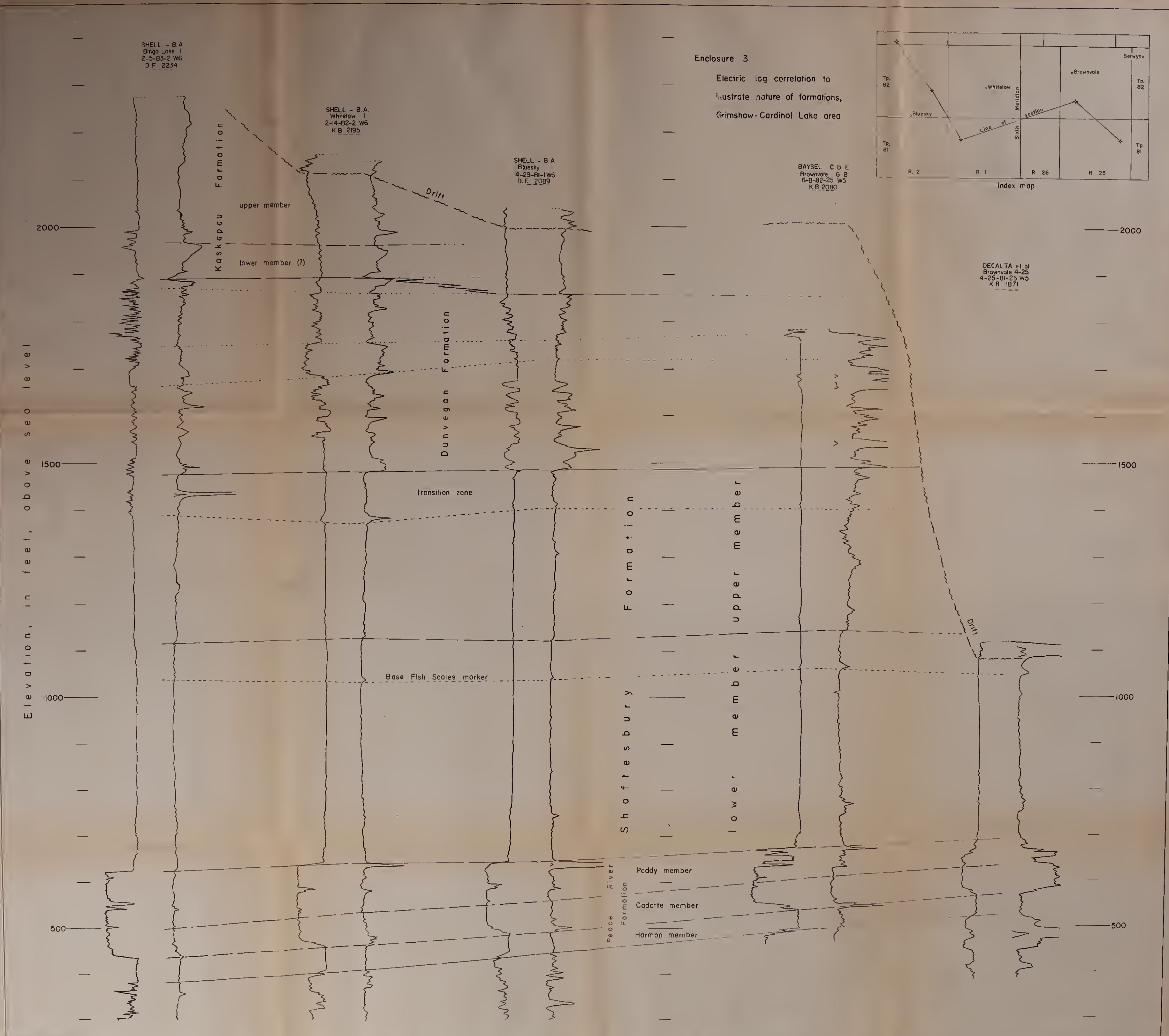
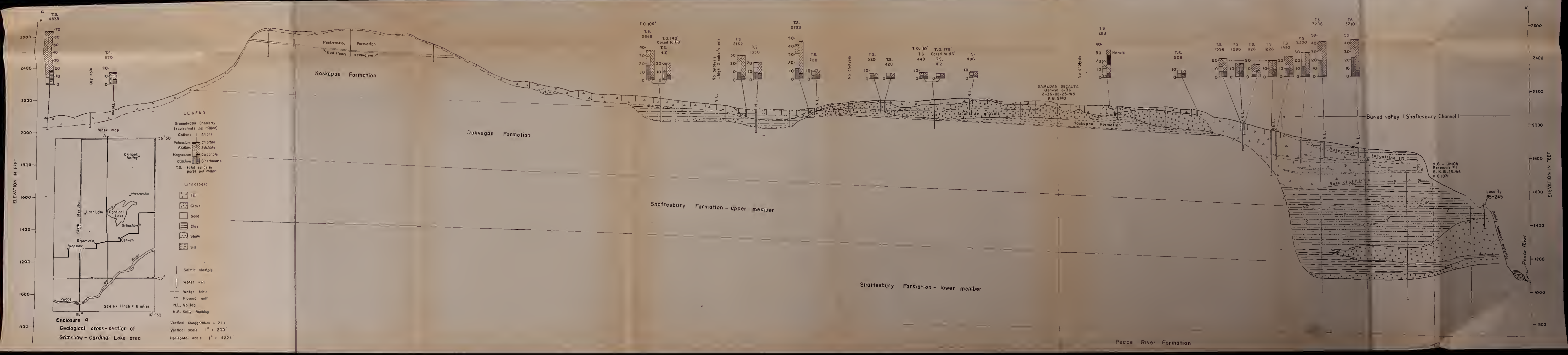
- Edge of escarpment; edge of river terrace.
- Geological boundary - definite
- Geological boundary - approximate



Enclosure 2
Extent and thickness of Grimshaw gravels
(Depth to top of gravel generally <30 feet)
LEGEND
Extent of Grimshaw gravels
boundary definite
boundary indefinite
45 Thickness of gravel and sand in feet
45+ Minimum thickness of gravel and sand
Seismic shothole gravel or gravel and sand present
Seismic shothole sand present
Seismic shothole - gravel and sand present probably of younger age than Grimshaw gravels
Seismic shothole gravel and sand absent
Water well penetrating gravel and sand (Selected wells only)
Testhole penetrating Grimshaw gravels
Testhole - Grimshaw gravels absent
Exposure of Grimshaw gravels
Spring out of Grimshaw gravels
R 25
R 24
R 23
R.22
R.21
R 26
R.1
Tp.86
Tp.85
Tp.84
Tp.83
Tp.82
Tp.81
SIXTH MERIDIAN
WHITEMUD
HILLS
Cardinal Lake
Lake St. Germain
Leddy Lake
Garfield L
Craven L
Lost L
Whitemud River
Peace River
Peace River Airport
Settlement River
Shaftesbury
Smoky R
Grimshaw
Berwyn
Brownvale
Whitelaw
Rama
Strong Creek
Cardinal Creek
Leddy
INDIAN RES
GSLR
NAR

Enclosure 3

Electric log correlation to illustrate nature of formations, Grimshaw-Cardinal Lake area



Enclosure 4
Geological cross-section of
Grimshaw - Cardinal Lake area

Enclosure 5

Bedrock topography

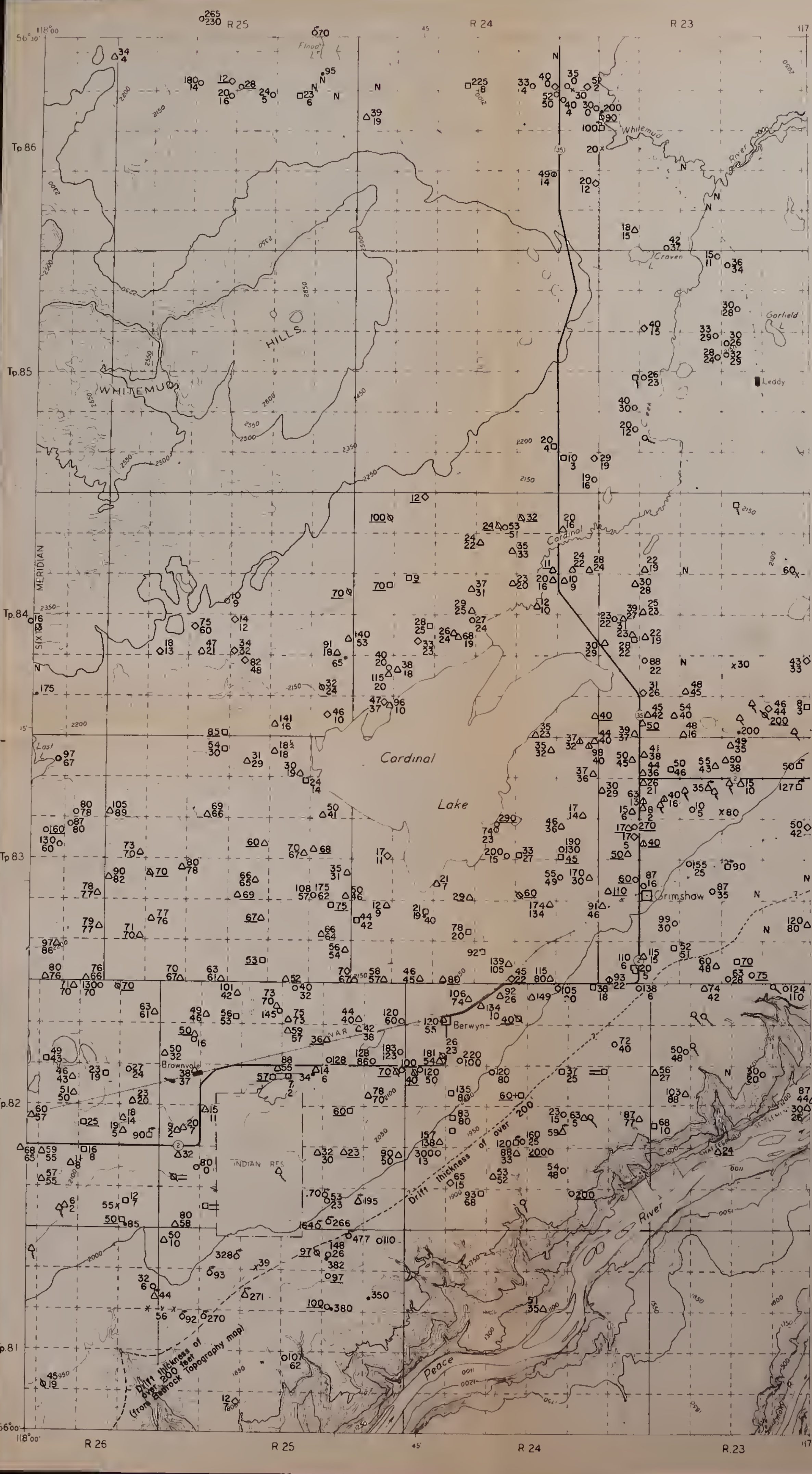
Grimshaw - Cardinal Lake area

LEGEND

Solid symbol indicates bedrock attained

Open symbol indicates bedrock not attained (only deeper holes shown)

- ● ○ Water well
- ◆ Structure testhole (e-log)
- Oil testhole (e-log)
- ■ □ Research Council of Alberta testhole
- Other testholes in which samples were collected
- Seismic shothole
- \+ Outcrop section - Drift
- x Outcrop - Bedrock
- ◆1701 Elevation of top of bedrock in structure testhole (feet above sea level)



Enclosure 6

Location of water wells, Grimshaw - Cardinal Lake area, showing depth and depth to water.

LEGEND

Well in:
- ○ Sand or sandstone
- △ Gravel
- ◇ Other; silt, clay, till, shale
- □ Aquifer not known

Spring

δ_{312} Δ_{91} $\square_{271}$ Flowing well and depth

x60 Flowing shothole and depth

Research Council of Alberta testhole

Well filled in

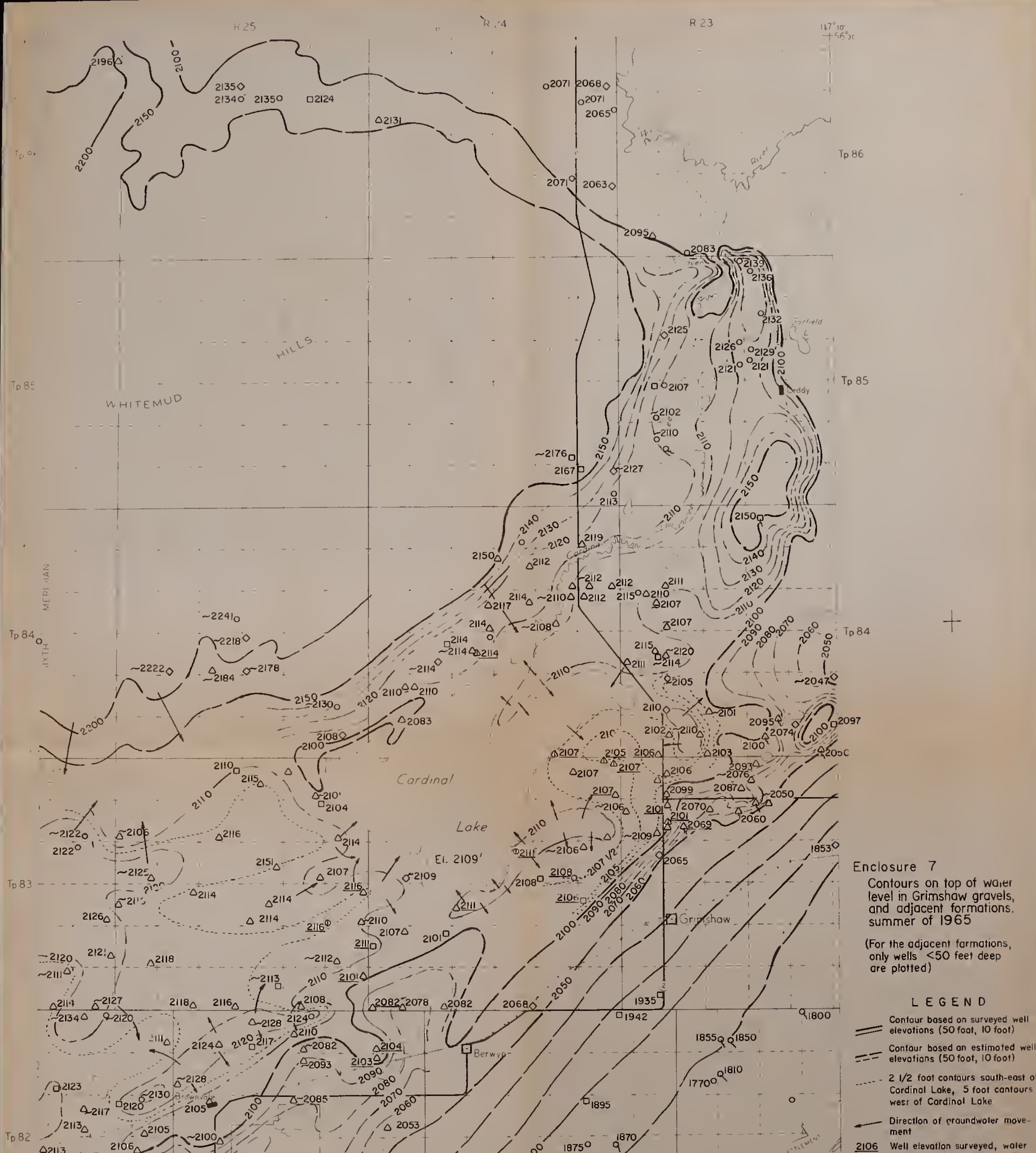
•200 Dry hole and depth

N No well - hauls water or uses other source

○ 100 / 96 — Depth of well / Depth to water from ground level

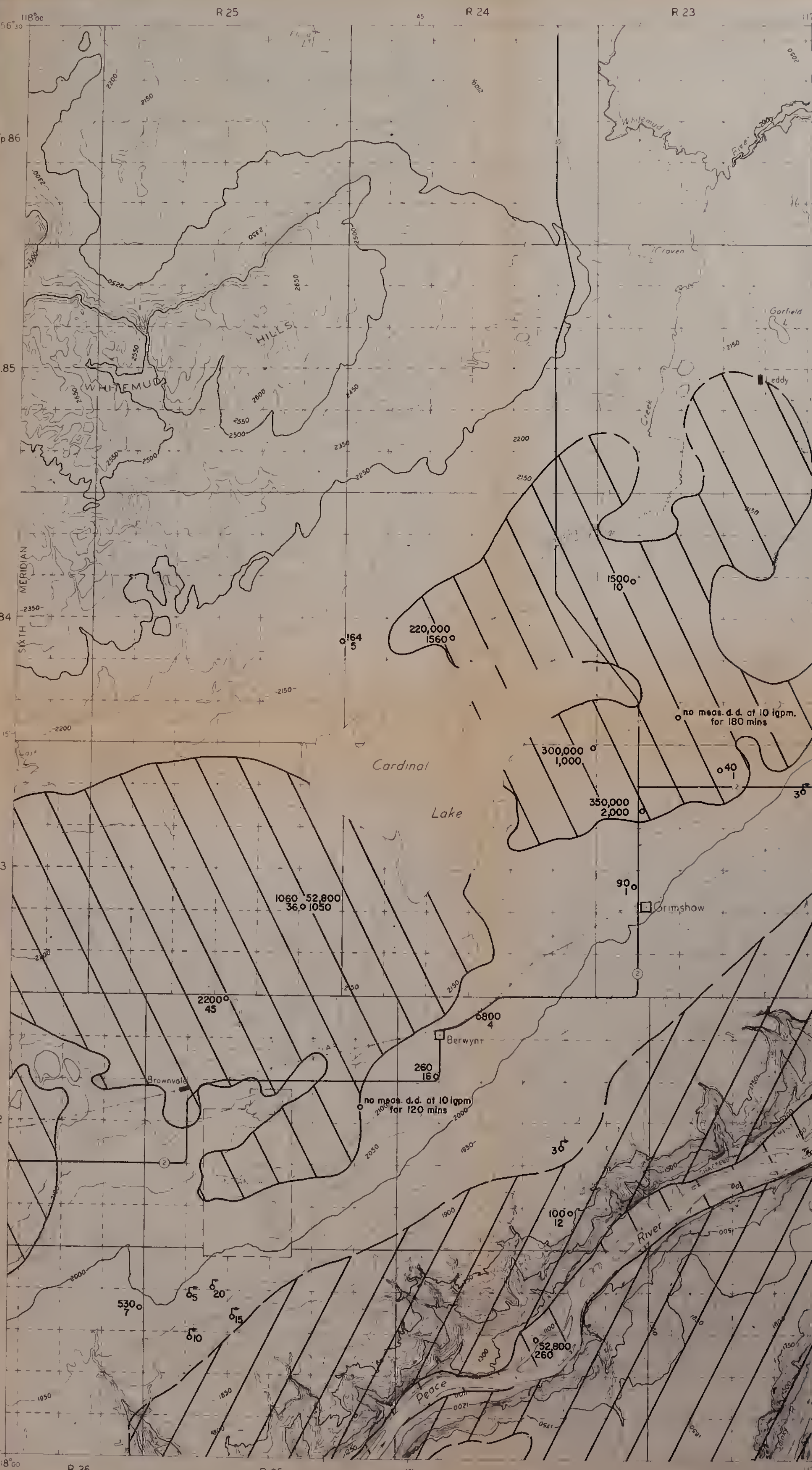
— Depth to water not known

□ — Depth of well not known / Depth to water not known



Enclosure 7
Contours on top of water level in Grimshaw gravels, and adjacent formations. summer of 1965

(For the adjacent formations, only wells <50 feet deep are plotted)



Enclosure 8

Groundwater probability Grimshaw-Cardinal Lake area

LEGEND

- Water well or test well
- 300,000 — Transmissibility or apparent transmissibility in Imperial gallons per day per foot
- 1,000 — Calculated 20 year safe yield in igpm.
- 15 Flowing well and rate of flow in igpm

Possible yields:

- <10 igpm
- 10-100 igpm
- >100 igpm

o no meas. d.d. - no measurable drowdown